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Subtask 6 – Flight Deck Guidelines for DAG-TM

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LIST OF ACRONYMS

ACAS	Airborne Collision Avoidance System
ACAD	Assured Collision Avoidance Distance
ACM	Airborne Conflict Management
ADI	Attitude Direction Indicator
ADS-B	Automatic Dependent Surveillance-Broadcast
ANSD	Assured Normal Separation Distance
AOC	Airline Operation Center
AOP	Autonomous Operations Planner
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Service
ATSP	Air Traffic Service Provider
DAG-TM	Distributed Air/Ground Traffic Management
CAZ	Collision Avoidance Zone
CD	Conflict Detection
CDM	Collaborative Decision-Making
CD&R	Conflict Detection and Resolution
CDTI	Cockpit Display of Traffic Information
CDU	Control Display Unit
CDZ	Conflict Detection Zone
CE	Concept Element
CNS	Communication, Navigation, and Surveillance
CP	Conflict Prevention
CPDLC	Controller Pilot Data Link Communications
CR	Conflict Resolution
CSD	Cockpit Situational Display
DST	Decision Support Tools
EADI	Electronic Attitude Direction Indicator
EGPWS	Enhanced Ground Proximity Warning System
EUROCONTROL	European Organization for the Safety of Air Navigation
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FAS	Flight Deck Alerting System
FMS	Flight Management System
FREER	Free Route Encounter Experimental Resolution
GPS	Global Positioning System
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
IVSI	Instantaneous Vertical Speed Indicator
LOS	Loss of Separation

MCP	Mode Control Panel
MOA	Military Operations Area
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
ND	Navigation Displays
NLR	Nationaal Lucht-en Ruimtevaartlaboratorium (National Aerospace Laboratory in the Netherlands)
NM or nmi	Nautical Miles
PANS-OPS	Procedures for Air Navigation Services – Aircraft Operations
PASAS	Predictive Airborne Separation Assurance System
PF	Pilot Flying
PFD	Primary Flight Displays
PNF	Pilot Not Flying
RTA	Required Time to Arrival
SA	Situational Awareness
SOP	Standard Operating Procedures
SSR	Secondary Surveillance Radar
SUA	Special Use Airspace
TA	Traffic Alert
TCAS	Traffic Collision and Alert System
TCP	Trajectory Change Points
TRACON	Terminal Radar Approach Control
VFR	Visual Flight Rules

1. PURPOSE

The purpose of this document is to identify display and flight deck features necessary for pilots to accomplish the tasks required for Distributed Air/Ground Traffic Management (DAG-TM) concepts, with emphasis on concept element (CE) 5 (En Route Free Maneuvering), CE 6 (En Route Trajectory Negotiation for User-Preferred Separation Assurance and Local TFM Conformance), and CE 11 (Terminal Arrival – In-Trail Spacing). The goal of the Flight Deck Guidelines is to implement the necessary features while minimizing the impact on existing cock-pit and display elements.

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2. SCOPE

This document describes the flight deck features necessary to enable pilots to complete en route and terminal arrival tasks as defined in NASA's DAG-TM concepts. Originally, the scope of this document was to address only cockpit situation display (CSD) features as they pertain to DAG-TM (Helbing, Mafera, Duley, & Legan, 2001). However, as the concept progressed, it became apparent that the needs of pilots would not be bounded to a single display. This document provides an understanding of the pilot information requirements, and methods through which information may be effectively communicated. Procedural, interface, and automation needs have been incorporated into this revision of the document to provide a comprehensive guide for flight deck considerations within DAG-TM.

Task analyses, based on a Detailed Description for CE 5 En Route Free Maneuvering (Phillips, 2000), Detailed Description for CE 6 En Route Trajectory Negotiation for User-Preferred Separation Assurance and Local TFM Conformance (Couluris, 2000) and a Detailed Description for CE 11 Terminal Arrival: Self Spacing for Merging and In-Trail Separation (Sorensen, 2000), were used to identify information requirements for each of the concept elements. A set of basic information requirements which is independent of any concept element was also developed. The information requirements, in turn, were used to derive necessary display and other flight deck features. Tables 1 through 3 (see Appendix) include the information requirements identified for basic display features, CE 5 and CE 11.

Airborne Conflict Management – This document presents an operational concept for the Application of Airborne Conflict Management (ACM) using Automatic Dependent Surveillance-Broadcast (ADS-B). The ACM concept includes detecting conflicts, monitoring for potential conflicts, and suggesting resolutions to prevent a violation of airspace separation criteria against all other properly equipped aircraft/vehicles. This concept was identified as Conflict Detection and Resolution (CD&R) in Helbing, Mafera, Duley, and Legan (2001).

ACM is a core enabling function for the global implementation of the *Free Flight* concept, as it will aid pilots to fly user-preferred trajectories while avoiding conflicts with other aircraft. The long surveillance range afforded by Automatic Dependent Surveillance – Broadcast (ADS-B) will enable alerts to be issued in time to solve the conflicts with minimum disruption to flight path. It is expected that the time provided by this extended range will allow for a variety of solutions, or optimized solutions, thus enabling the choice of user-preferred trajectories while avoiding conflicts with other aircraft (RTCA, 2000).

Format of Guidelines – Section 3, Operational Environment, describes the general environment where the flight deck guidelines may be applied. Section 4, Flight Deck Operations, provides an overview of some global issues that designers should consider in the development of a flight deck suitable for DAG-TM. Section 5, General Human Factors Considerations, describes basic human factors principles that should be considered in display design. These principles represent characteristics that are fundamental to usable design. Section 6, Basic Display Features, discusses in detail display features that are independent of any specific CE, mode, or phase of flight. They are features that are generally present on the display at all times. Section 7, En Route Free Maneuvering, discusses features that are specific to providing pilots the capability to free maneuver. Similarly, Sections 8 and 9 describe features specific to Trajectory Negotiation and Terminal Arrival, respectively.

The guidelines conform to a general format. Distinct display or flight deck features that require discussion are addressed individually. Some features may require discussion of several topics – color, symbology, etc. A description of the current display or functional convention, if applicable, is provided. The discussion is followed by specific recommendations for each feature. Because many of the features are new, often there are no existing data pertaining to them. In these cases, a description of feature or information need is provided, and recommendations are made based on current knowledge. Often, the recommendation describes the need for additional research. This document will be updated to reflect changes in recommendations as research and experience dictate over the remaining two years of the project.

Many of the display features are common to existing aircraft navigation displays (NDs), and numerous existing references detail requirements or recommendations for these features. In the interest of focusing on new display features, details pertaining to well-documented display issues will not be provided. Rather, a list of references is provided, and readers should refer to this list to find relevant documentation.

Finally, figures depicting representative display features are provided throughout the document. The figures were produced to provide appropriate color representations when viewed on a 1024 x 768, 32 bit color monitor. Note that color variations may result due to differences in color monitor settings and capabilities. Printed versions of the document may contain color aberrations.

3. OPERATIONAL ENVIRONMENT

DAG-TM is a proposed solution to expanding airspace capacity limits. DAG-TM alters the roles and responsibilities of the stakeholders in order to permit more user-preferred routing, increased flexibility, increased system capacity, and improved operational efficiency. DAG-TM is based on the fundamental premise that all system participants can be information suppliers and users, thereby enabling collaboration and/or distribution at all levels of traffic management decision-making. This new environment will achieve successful operation through new human-centered operational paradigms enabled by procedural and technological innovations. These innovations include Decision Support Tools (DSTs); information sharing; and communication, navigation, and surveillance (CNS)/Air Traffic Management (ATM) technologies.

In some phases of flight in the DAG-TM environment, the role of the air traffic service provider (ATSP) is to define the operating constraints. The role of the pilots is to avoid conflicts with other aircraft or airborne hazards (e.g., special use airspace, weather) by maintaining separation and meeting the ATSP’s imposed constraints (e.g., required time of arrival). A conflict is defined as the intrusion by one aircraft into another aircraft's protected zone[1], resulting in a loss of separation. In order to accomplish aircraft self-separation, the National Airspace System (NAS) requires technologies to support ACM. ACM, the core-enabling function of the DAG-TM paradigm, will assist pilots in flying user-preferred trajectories while avoiding conflicts with other aircraft. To maintain separation, pilots will use aircraft position and trajectory information exchanged between aircraft via ADS-B. The long surveillance range of ADS-B will enable the issuance of conflict alerts in time to solve conflicts with minimal flight path disruption (RTCA, 2000). It is expected that the amount of time provided by ADS-B will offer pilots a variety of solutions that they may optimize for user-preferred trajectories, fuel efficiency, or time.

The pilots must use a cockpit display of traffic information (CDTI), a CSD, or another form of traffic information presentation to enable self-separation from other aircraft. The CSD is the critical link between the flight crew, Flight Management System (FMS), digital datalink, collaborative maneuvering with other aircraft, and collaborative decision-making (CDM) among the flight decks, ATSPs, and Airline Operation Centers (AOCs). Yet workload and the difficulty of perceiving potential conflicts at various intrusion geometries (e.g., Palmer, Jago, Baty, & O'Connor, 1980) keep a pilot/flight crew from accurately detecting all potential conflicts and resolving such conflicts efficiently, without aid from a form of decision support. Using the aircraft surveillance capabilities of ADS-B, ACM offers decision support in the form of CD&R. Therefore the pilot/CSD interface consists of the ADS-B traffic information *and* the CD&R algorithms. Both aspects must be considered with respect to human performance in designing an effective DST to enable DAG-TM.

Three DAG-TM concept elements are currently being investigated for feasibility. CE 5, *En Route Free Maneuvering*, provides for appropriately equipped aircraft to be able to maneuver freely in en route airspace. Free maneuvering aircraft have the authority to make trajectory changes with the restriction that no new conflicts are created by their maneuvers within a defined period of time. To accomplish this, aircraft must transmit their position and intent to enable conflict

[1] *The aircraft's protected zone is defined by the minimum separation requirements as identified in FAA 7110.65.*

detection and resolution by other free maneuvering aircraft and the ATSP. Free maneuvering aircraft have DSTs that enable situation awareness, allow flight crews to maintain separation from other aircraft without ATSP assistance, and provide trajectory re-planning capabilities (Phillips, 2000).

CE 6, *En Route Trajectory Negotiation*, is concerned with the interaction among the DAG-TM stakeholders (pilots, ATSP, AOC) when a trajectory change is initiated in response to potential conflicts and concurrently conform with local Traffic Flow Management (TFM) constraints. During trajectory negotiation, the role of the ATSP is to define the operating constraints and to retain full responsibility for separation assurance. The role of the pilot in CE 6 is to avoid conflicts with other aircraft or airborne hazards (e.g., special use airspace, weather) by maintaining separation and meeting the ATSP's imposed constraints (e.g., adhering to traffic flow management constraints). In CE 6, the AOC defines airline constraints and preferences (related to fuel efficiency, reduction of delays, or passenger comfort) that are considered in the trajectory changes and may initiate both long- and short-term trajectory changes. In the current concept description, the AOC-defined constraints and preferences are transmitted to the ATSP and FD. In a pilot-initiated trajectory negotiation, the FD DST is requested to compute a feasible resolution within the constraints defined by the AOC, pilot, and TFM limitations. The FD transmits the proposed trajectory to the ATSP, where it is then assessed by the ATSP. When the proposed trajectory change is approved, the ATSP issues a clearance to the pilot. The new trajectory is loaded into the FD FMS and is automatically broadcast to other aircraft.

The communication and negotiation among stakeholders in CE 6 ensures that requirements of all stakeholders are considered. Trajectory changes may be initiated by any of the stakeholders, but ultimate responsibility for separation will remain with the ATSP (Couluris, 2000). Because successful user-preferred trajectory negotiation within the given airspace constraints depends on real-time collaboration among the pilot, ATSP, and AOC, CE 6 focuses on procedural elements of the tasks, as well as display and information requirements for the various stakeholders.

Finally, in CE 11, *Terminal Arrival: Self-Spacing for Merging and In-trail Separation*, flight crews maintain closely spaced operations in the terminal area [beginning outside the Terminal Radar Approach Control (TRACON) and ending at the Final Approach Fix (FAF) during Instrument Meteorological Conditions (IMC)]. Three modes of operation have been identified (Sorensen, 2000):

- Free maneuvering
- Merging
- Spacing

During the initial arrival phase of flight, appropriately equipped aircraft (with CSDs and DSTs) are permitted to free maneuver and generate their flight paths within a defined approach corridor leading to the future merge point. In the free maneuvering phase, the flight crew is responsible for self-separation longitudinally only, similar to CE 5 operations. In the merging phase, multiple aircraft and their routes are merged into a stream of traffic. Equipped aircraft are responsible for adjusting their in-trail position consistent with merging into the stream of traffic followed by proper spacing behind the designated lead aircraft. In the spacing phase, flight crews are responsible for maintaining a specified temporal separation from the designated lead aircraft in the same stream of traffic to the designated runway. Display symbology and DSTs will assist the pilots in maintaining this separation.

4. FLIGHT DECK OPERATIONS

Proposed DAG-TM operations depart significantly from current Standard Operating Procedures (SOPs). Traditional phases of flight and airspace divisions are redefined. Information that was previously not provided to pilots will now be available during flight. The redistribution of the roles and responsibilities among the airspace users (pilots, ATSPs, and AOC dispatchers) results in a shift of information requirements for the different users. These changes also require that procedures be developed to ensure that each user knows his or her area of responsibility and has guidance in carrying out these responsibilities. Several general issues related to FD operations are discussed below.

4.1 STANDARD OPERATING PROCEDURES

With the implementation of a CSD and CD&R via secondary surveillance or dependent surveillance technologies, there is a need for standard operating practices that govern the use of the information on a CSD as well as pilot performance in the event of a failure of this technology. A recently proposed International Civil Aviation Organization (ICAO) Procedures for Air Navigation Services – Aircraft Operations (PANS-OPS) amendment is expected to establish a number of human factors related provisions for FD procedures (Maurino, 2001). In particular, one area that the amendment addresses is SOPs. The PANS-OPS would require that air transport operators establish SOPs that provide crews with guidance in carrying out flight tasks. The proposed amendment requires the SOPs to unambiguously express each flight task as a standardized procedure including the timing and sequence. The SOPs would define by whom the task is to be conducted, how it is to be performed, the sequence of actions to be performed, and the type of feedback to be provided (i.e., verbal call-out, instrument indication, switch positions, etc.).

General Procedures: To date, SOPs have not been investigated with respect to the use of a CSD. However, in performing the Safe Flight 21 operational evaluations (FAA, 2000b), researchers implemented the following procedures that relate to the use of a CSD:

- *Turn transponder ON during preflight cockpit setup. Transponder remains ON during all operations.* This procedure is a necessity as current practice is to not turn on the transponder until just prior to the take-off roll.
- *Determine taxiway/runway/final approach is clear by looking out window*.
- *Responses to traffic call-outs must be based on looking out the window. Do not call traffic in sight based solely on CSD*.
- *No evasive maneuvers are authorized as a sole result of targets displayed on CSD traffic alerts* (TAs). This requirement is similar to a response to Traffic Collision and Alert System (TCAS) traffic and resolution advisories. The flight crew responds to traffic advisories by attempting to establish visual contact with the intruder aircraft and other aircraft that may be in the vicinity. The crews then coordinate to the degree possible with other crewmembers to assist in searching for traffic. The flight crew is not to deviate from an assigned clearance based only on traffic advisory information. However, when a resolution advisory occurs or the pilot is responding to a conflict alert, the pilot flying should respond immediately by direct attention to resolution advisory displays and maneuver as indicated unless doing so would jeopardize the safe operation of the flight. This is also the case if operating in the approach environment where the flight crew can assure separation with the help of definitive visual acquisition of the aircraft causing the resolution advisory.

Communications in an automated FD differ from traditional communications. For example, in traditional procedures, the pilot flying (PF) may make a request to the pilot not flying (PNF) (e.g., extend the landing gear), who initiates a specific action with a salient result (e.g., moves the landing gear handle). The PF can check the PNF actions by observing the response. In an automated system, actions are often made through a computerized system where it is not obvious whether the input is made, or if it is entered properly (Orlady, 2000). For example, the PF may be cleared to follow in-trail at a 90 second interval. The PNF would then enter this number into the CDU. However, the incorrect number could easily be entered and the PF would have no method to check the inputs. Procedures must be developed to avoid such errors and to ensure that both pilots are aware of inputs made by the other pilot (Orlady, 2000).

An additional issue for research with respect to the need for SOPs is the event of a failure mode. Phillips (2000) identified several failure modes that may occur in the en route environment. Some of the failure modes that relate to the use of CSD information are:

- Dependent surveillance transmission errors, e.g.,
  - Lacks intent (FMS flight plan) or performance information
  - Sends incorrect intent (FMS flight plan) information
  - Mode errors
  - Intentional mode changes
- Conflict resolution fails to find a resolution
- Display failures

Traffic Callouts: Human-in-the-loop evaluations conducted in Europe have implemented SOPs for communications between the ATSP and pilots when making traffic callouts or conveying instructions for in-trail spacing. Van Gent, Sinibardi, Cloerec, Vaccaro, and Pasarelli (2000) have documented the traffic identification phraseology used in the Free Route[2] Encounter Experimental Resolution (FREER) evaluations. The phraseology incorporates the use of secondary surveillance radar (SSR) or beacon codes in the identification of traffic. Two examples of traffic identification are presented below (van Gent, et al., 2000, p. 209).

[2] *Free-routing is the European equivalent of Free Flight or advanced air traffic management concepts.*

Identification with positioning by controller:

- **Controller**: "DLH456, select target 1234, (3 o'clock / right to left / 30 NM /1000ft above)"
- **Pilot**: "Selecting target 1234, DLH456"
- After the pilot selects and identifies the target on the CSD:
- **Pilot**: "Target 1234 identified, DLH456"

Identification with positioning by pilot:

- **Controller**: "DLH456, select target 1234, position target"
- **Pilot**: "Selecting target 1234, DLH456"
- After pilot selects and identifies the target on the CSD:
- **Pilot**: "Target 1234 identified, 3 o'clock / 30 NM / FL250 / 1000 ft. above, DLH456"

The use of the SSR code for traffic identification potentially alleviates the confusion that may be created by identifying traffic by call sign. Since pilots are trained to respond to their own call sign, the traffic aircraft flight crew will respond to hearing ownship's call sign even though the communication is not directed to ownship. Such events will become more common as the DAG-TM concept develops.

Additional research is needed to determine if using both call signs and SSR codes in traffic callouts is a feasible solution with respect to broadcasting callouts on the FD. Because some of the communication may become cumbersome (e.g., "Target 1234 identified, 3 o'clock / 30 NM / FL250 / 1000 ft. above, DLH456"), procedures must be evaluated in terms of human error potential. These errors must be weighed in terms of errors resulting from using traditional call sign communications.

4.2 DECISION-MAKING: STRATEGIC VS. TACTICAL

Before and during a flight, there are two general categories of decision-making. The first concerns long-term planning – deciding on the best route to take from point A to point B, considering known parameters such as weather, airspace restrictions, and fuel economy. This type of planning is *strategic* in nature – it allows the pilot to develop the most economical and safe strategy to complete the flight. The pilot can generally develop the strategic plan before the flight begins and file the plan with air traffic control (ATC).

The second type of planning results as a response to unexpected or emergency conditions, such as avoiding a conflict or circumventing weather cells. This type of *tactical* planning is a short-term solution to resolve an immediate problem – there is less concern with issues such as fuel economy and is usually related to safety of flight.

4.3 PHASES OF FLIGHT: EN ROUTE VS. TERMINAL ARRIVAL

Because the different phases of flight (departure, en route, arrival) require different types of information, it is likely that some of the required CSD information will differ significantly. For example, it is not necessary to reserve space on the display to indicate spacing requirements for in-trail spacing during the en route phase of flight. It is possible that several different display modes will be required because of the different types of information and symbology required for the different phases of flight.

There are several methods by which mode changes could be implemented during flight. Pilots could manually select a specific mode at the appropriate time during the flight. This type of implementation would give the pilot control over when a certain mode should be initiated. Conversely, pilot initiated mode selection requires the pilot to be vigilant as to when it is appropriate to switch modes. However, implementation of SOPs or checklist items for mode selection at the transition for phase of flight could reduce the vigilance and workload required for task completion.

Alternatively, mode changes could be fully automated. Other than emergency situations, specific phases of flight generally occur in a relatively predictable sequence: departure, en route, terminal arrival, and landing. Because flight plans will be programmed into the FMS, transition points may be identified at which mode changes may be anticipated. Displays could automatically update to include only the information and symbology required for that particular phase of flight. This type of implementation would reduce pilot workload since pilots would not need to monitor the progress of the flight to determine if a mode change is necessary. However, automatically changing modes could cause confusion and loss of situational awareness (SA) if the pilot was not mentally prepared for the mode change and corresponding change in the look of the display.

As a compromise to the methods described above, mode changes could be manual, with an automatic prompt indicating to the pilot that a mode change should be initiated. The system could also indicate which mode should be implemented, and allow the pilot to simply accept or reject the suggestion. This approach would ensure that the pilot would select the appropriate mode at the proper time, yet would still give the pilot control over when the change will occur. The feature should time out after a certain amount of time if there is no response from the pilot.

A final alternative to implementing specific modes, context-sensitive symbology could be tailored for specific phases of flight. In a context-sensitive approach, information is displayed based on its relevance to the current situation. Woods, Patterson, and Roth (1998) describe a sharpening technique that uses “local outposts of contextual data” (p. 28) to determine what information should be displayed at any point in time. From a FD perspective, these data would be the relationship of intruder to ownship and the type of airspace (i.e., en route, terminal, etc.).

4.4 DYNAMIC DENSITY

Contrary to the previous Section’s recommendations, it should be noted that display modes and operational procedures may not correspond precisely to flight phases, or even types of airspace. Dynamic Density (DD), a method for defining airspace complexity and air traffic controller workload (Lauderman, Shelden, Branstrom, & Brasil, 1998), may be used to define operational procedures and rules in the future. Factors that are included in DD are traffic density, air traffic complexity, and separation standards within a volume of airspace (Kopardekar, 2000). A number of factors (Kopardekar lists 40) contribute to air traffic complexity and researchers are currently attempting to identify their impact so that they can be integrated into a single measure of traffic complexity. The degree of control over the airspace from air traffic management may vary as DD varies.

If DD rules are in effect, and air traffic management imposes different levels of control over an airspace depending on the number of aircraft and/or the complexity of their trajectories, different display modes may be appropriate even in the same airspace or phase of flight. Consideration should be given to the possibility that display modes and operational procedures should be related to the degree of air traffic management control being exerted, as well as flight phase and airspace type. This is because the pilots' responsibilities and decision support requirements will depend partly on the level of ground control.

5. GENERAL HUMAN FACTORS CONSIDERATIONS

This section discusses general human factors principles that are relevant to CSD design. The objective is to determine what information the pilot needs at what times during his tasks. Once the *what* and *when* have been determined, the *how* must be considered. How should the information be displayed so that the pilot is able to quickly extract it and accurately fit it into his mental model? Some basic principles related to *how* are provided in this section, and details are provided as they pertain to specific features throughout the remainder of the report. Special consideration is given to reducing display clutter, minimizing heads-down time, automation and voice input.

5.1 SALIENCY OF DISPLAY FEATURES

All of the information presented on the cockpit displays is designed to improve the pilots' SA. SA includes factors such as knowing the location of ownship (in relation to waypoints, flight plan), knowing the locations of traffic aircraft, weather, or restricted areas, knowing the intent of traffic aircraft, and the risk of conflict with any of these other aircraft. SA includes spatial orientation and near-future predictive components involving both long- and short-term memory (Lehman & Jenkins, 1990). In attempting to provide complete information to ensure SA, large quantities of data must be available to the pilot. However, a pilot may be quickly overwhelmed by the volume of data available. It is therefore critical to carefully select the most relevant data to be presented at any given point during a flight.

When designing a display, what information should be displayed, and when it should be displayed, are crucial in determining the layout of the information. Tables 1 through 4 in the Appendix address these issues for basic display features and CEs 5, 6 and 11. The descriptions below refer to the terminology in these tables. In determining *what* information should be more prominent on the display, the main consideration is the importance of the information for that particular phase of flight (i.e., what information the flight crew need to maintain SA right now). A second feature that must be considered is *when* the information should be presented. Should all pieces of information be displayed continuously? If only a few pieces of information are required, as in a fuel quantity display, this may be an option. However, in a complex system such as one enabling the pilots to maintain self-separation, the amount of information required to complete the tasks would quickly clutter the display to the point where it would not be usable. Care must be taken in determining which pieces of information should be displayed during each phase of the flight. The proposed system can provide the PF and PNF with active control of the complexity and density of the information through direct control of filters or modified thresholds matched the DAG-TM system. These filters could temporarily mask information such as weather, distant traffic, detailed traffic text, for example if needed to focus on other display elements. For other examples, see Section 5.2.

5.1.1 Importance of Information

Primary – In Tables 1 through 3, *primary information* consists of information that is required for normal operations and alerting information indicating emergency or abnormal conditions.

Information that is currently displayed under normal operations on existing navigation displays is the baseline for primary information for DAG-TM. These data consist mainly of basic navigational features. Newly implemented display features will be assessed to determine if they are of primary or secondary importance.

In addition to navigational features, safety features are considered primary information requirements. Three levels of FD alerting described in SAE ARP4102/4 (1999) are in the primary information category:

- Level 3 Alert (Warning) – indicates an emergency situation, such as the aircraft being in a hazardous situation, or serious system failure.
- Level 2 Alert (Caution) – indicates an abnormal situation, such as a system malfunction that has no immediate impact on safety.
- Level 1 Alert (Advisory) – indicates a recognition, or call out, of a situation, such as loss of system redundancy.

For DAG-TM, all alerting features are primary information, as are resolutions to the alerts. (Visual alerting methods for CSD are described in section 7.2.1 under Conflict Detection.) Several other features pertaining to free maneuvering operations fall into the category of primary information.

Primary display information demands attention and should be emphasized by occupying a prominent position on the display. Research indicates that attention bias to display locations in a visual search task depends on the type of task being performed (Johnson, Liao, & Tse, 1999). Therefore, information that is important for a particular task should be located in the center of the field of view. The displays used for DAG-TM should therefore be centered in front of the pilots. Within the displays, information similar to existing display information should follow convention. *The position of new data on the display is a topic of research.*

Color coding is an effective method of indicating the level of importance of information (e.g., red indicates stop or high level alert), to group same-type information (e.g., wind speed and direction information is all displayed in white), or to emphasize certain pieces of information. Color coding is particularly effective on unformatted, high density displays where it is important for the user to distinguish relevant information from other display features (Wiener and Nagel, 1988), such as a CSD. When using color coding, however, care must be taken so that it is not over used and that FD color standards are not violated. Using more than six colors for color coding is not recommended (Doc 9758-AN/966, 2000). From a pilot's perspective, a two color coding scheme is highly desirable. One color should indicate immediate action required. The other color should indicate no action required. That is, the ownship pilot should have an unambiguous indication as to whether or not he needs to respond in a given situation.

Secondary – Secondary information is supporting information. It does not include safety of flight information.

One level of FD alerting described in SAE ARP4102/4 (1999) is in the secondary information category:

- Level 0 Alert (Information) – information only that does not require pilot response (SAE ARP4102/4, 1999).

5.1.2 Information Presentation

Always – Information which is continuously shown on the display. It is not user selectable. For example, the compass rose (with the current magnetic heading) is always present on the ND as is the position of ownship.

Selectable – Features which the user can hide or display at his or her discretion. The controls and methodology to enable selectable features must be carefully implemented to minimize workload and heads-down time.

System Applied/Context Specific – Some types of information are relevant only at certain points during a flight. Features that are always present may vary depending on the operational mode, phase of flight, dynamic density or selected range of a ND. For example, guidance features may only be necessary to aid the pilot in approach spacing. Some of these features may be implemented automatically, without user input – alerts, for example, should be displayed at any point during a flight without user input. “The alerts shall be adapted to the Flight Phase according to ARINC 726. Alerts that are unrelated to a specific flight phase shall not be inhibited or downgraded” (SAE ARP4102/4, 1999, p. 2). Other features that are relevant only to specific phases of flight and may be implemented by selecting a certain mode – spacing guides, for example, may be implemented in the terminal arrival mode.

A feature may be of primary importance, yet still be system applied. Alerts are a good example of features that, when they are applied by the system, must be given primary importance.

5.2 REDUCING DISPLAY CLUTTER

Showing all available symbology can add significant clutter to the display. It is not necessary for pilots to see all of this information at each stage of the flight. In fact, in some cases, such as on some Boeing aircraft, selecting the option to display all airports and navigational aids on the moving map can overload the system, resulting in the display of "excess data" on the display (Orlady, 2000). Such situations should be avoided.

Some semi- and fully-automated methods for reducing the amount of information presented on the display were discussed in Section 4.3, Phases of Flight. However, pilots have expressed a desire to selectively remove some symbology from the screen to reduce clutter (e.g., van Gent, et al., 2000). Several methods are recommended to aid in clutter reduction. When pilots have the option to display several features, directives regarding the amount and type of information on the display are not provided in the standard operating procedures (SOPs) (Orlady, 2000). Providing SOPs to guide pilots on the appropriate use of information may be useful in aiding the pilot to determine which display features are useful at a particular point or situation in the flight without resulting in clutter.

Display Range: The more airspace that is represented on the display, the greater the number of traffic aircraft that will be presented. Pilots can reduce the amount of clutter by decreasing the displayed range. Such range-filtering was implemented in the Airborne Use of Traffic Intent Information (AUTRII) study at NASA Langley were pilots were observed to change range settings frequently when assessing the traffic situation (Wing et al., 2001). A maximum display range of 160NM is recommended for low traffic density areas and for a weather situation display (van Gent, et al., 2000). However, since much of the information on which pilots will depend for free flight or DAG operations will come from ADS-B, this maximum display range should consider the maximum proposed range for ADS-B.

Altitude Filter: It is likely that only aircraft within a particular reduced range of airspace surrounding ownship could cause a significant threat. An altitude filter would allow pilots to view only aircraft that are within a defined range from ownship, thereby reducing clutter. Pilots should be able to select the displayed range of traffic, for example ±3000 ft around ownship. The filter should have a minimum displayed range set to a level that ensures that a pilot cannot accidentally filter out all of the traffic aircraft. The pilot should be able to return to an unfiltered condition in a single action, so that all traffic aircraft will be displayed immediately. Any aircraft that causes an alert should be presented on the screen, regardless of the filter setting.

Removing "Non-Threatening" Aircraft from Display: Another form of filtering could eliminate aircraft that are out of range to cause a potential threat. Aircraft that are above ownship and are climbing, or are behind ownship headed in the opposite direction, for example, will not cause a threat in the near term. An operational trade-off is that this feature may make flight re-planning difficult due to the inability to consider positions of all aircraft.

Declutter Implementation: Pilots should have the option to selectively remove CSD information from the display (ARP 5365). This function should be completed by a simple action. Since some aircraft will not have cursor control devices, alternative methods must be developed to allow pilots to select information.

Bezel buttons – Multi-function buttons, such as those on the control display unit (CDU), allow the functionality of the button to change depending upon the particular page displayed on the screen. For example, pilots select whether or not they want aircraft IDs to be displayed via these buttons. An advantage to this type of implementation is that it allows existing panel features to be reused, minimally impacting the complexity of the FD. The disadvantage is that it requires pilots to know how to navigate through the pages to arrive at the appropriate page to achieve the desired change.

Dedicated button on panel – Some systems, such as the NASA Langley CSD, enable pilots to select all aircraft IDs by pressing a designated button, e.g. "ACID", from a control panel. One press of the button shows all aircraft IDs, without the enhanced data tag. A second press of the button hides all the aircraft IDs. An advantage to this type of implementation is that pilots may access the button directly, without needing to go through screen pages or a menu structure. A drawback is that adding separate buttons for each function will soon clutter the panel.

Touch Screen – When looking at a display with several features, such as one cluttered with traffic aircraft, the most natural method to select an aircraft is to point at it. Touch screen technology would enable pilots to simply touch the desired aircraft symbol to select that aircraft. This method allows pilots to see directly the result of their action. However, a pilot's ability to accurately point to a spot on the screen may be compromised if the screen is cluttered or there is turbulence. Furthermore, touch screens have been frequently evaluated and rejected for aviation use because oils from the fingertips can obscure the display, particularly in sunlight.

Menus – Traditional menus allow access to numerous options with little use of space. The structure of the menus must be carefully considered, so that options may be easily accessed with minimal user interfacing. Also, the method in which these menus would be implemented must be studied, as different implementations may be more or less appropriate for different cursor control devices or for no such device at all. However, menu choices for conflict resolution are highly desirable due to the pilot's perceived need to be in control of the conflict resolution strategy.

5.3 MINIMIZING HEADS-DOWN TIME

One issue that pilots mentioned during the NASA Ames DAG demonstration in September 2001, was the excessive amount of time spent heads down during CE 6 operations (Kopardekar, Sacco, & Shelden, 2001). The large amount of time spent heads down could have a potential negative affect on overall situational awareness. A pilot who spends an excessive amount of time looking at features on the cockpit instruments and displays may not be fully aware of events occurring on the other side of the windscreen.

In an effort to reduce the amount of pilot time spent heads down, the following general human factors guidelines should be followed (selected from Mejdal, McCauley, & Berringer, 2001). Note that these principles are applied throughout the document.

- Present only the information that the pilot needs, in a simple format, when the pilot needs the information
- Provide *information*, not *data, in a usable form*. Do not require the pilot to transpose, compute, or interpolate displayed data (implement at-a-glance information)
- Maintain consistency in display formats, location of information on the screen, vocabulary, labeling, graphical formats, and coding
- Provide feedback to a pilot's inputs and to indicate system response to the input
- Link related items and disassociate unrelated items through their size, shape, color, or texture
- Employ color to focus the pilot's attention on critical information
- Design displays to minimize eye movements
- Employ automation to reduce the pilot's need to interact with systems or interpolate data

Care must be taken with regard to the implementation of automation. Several issues are discussed below.

5.3.1 Automation Issues

Automation may have a role in the implementation of a CSD for a single pilot or two-to-three person flight crew. Automation may be implemented in the form of information acquisition or information analysis. The automation of information acquisition applies to the sensing and recording of input data such as the presentation of updated traffic position information. Automation may be applied here in the sense of organizing the information for the flight crew (Parasuraman, 2000). Some of these organizing methods are described in the following sections regarding highlighting Section 6.2.1) and filtering (Section 5.2) of information or providing context specific information (Section 6.3.9). Automation of information analysis may take the form of prediction such as the prediction of future positions for traffic aircraft (see Section 5.3.1).

In the case of either type of automation, the design approach should consider the human performance costs and benefits particularly in the areas of mental workload, SA, complacency, and skill degradation (Parasuraman, 2000). There are numerous empirical and quantitative models that may be used as guides in the application of automation for DAG-TM. These issues are of particular concern to the development of a CSD as the objective of such a decision support tool is to increase situation awareness without increasing workload to the detriment of flight performance. The design must consider that many of the DAG-TM concepts re-distribute workload from the ATSP to the flightdeck and therefore use of a CSD must not create unnecessary additional cognitive workload for a single-pilot or a two-to-three person flight crew.

It should be recognized that automation may lead to certain kinds of human error and failure scenarios. For example, mode errors (Sarter & Woods, 1995) are well documented causes of incidents and accidents. In an Actual Navigation Performance/Required Navigation Performance environment, where aircraft must maintain a certain level of flight path precision in order to have access to certain classes of airspace, pilots are likely to rely exclusively on automation, increasing the potential for automation related error. For these reasons, the intent being broadcast by an aircraft may not be accurate. Riley (1996) describes a number of scenarios where intent statements may be misleading. If intent is determined (as in ADS-B) by an extrapolation of the current trajectory for some future distance or time, but the aircraft is following the FMS flight plan, the extrapolated trajectory would be misleading. If the aircraft broadcasts intent based on the contents of the flight plan, but the pilot is flying in a tactical autopilot mode (heading, flight level change, vertical speed, etc.), the intent would also be misleading.

Furthermore, mode errors combined with intent statements may lead to complex loss of coordination between ATSPs, pilots, and aircraft. If a pilot intends to command a particular trajectory but, due to a mode error, commands a different trajectory, and the aircraft broadcasts intent based on mode selection, everyone may be aware of what the aircraft will do except for the pilots operating it. If intent statements are not mode-specific but rather based solely on the flight plan contents, then none of the people or systems involved in a situation will accurately anticipate what the aircraft will do.

Future Position Uncertainty: For the reasons described above, depictions of future positions should recognize the uncertainties inherent in those predictions. Wind uncertainties alone prevent accurate predictions of future climb and descent profiles and fuel use; when human and system error potentials are added, future position projections become inherently unreliable. Precise depictions of future position can therefore be misleading, but precise depictions on a visual display can be very compelling. This leads to the possibility that a future position indication that appears to be more precise than is warranted by the uncertainty of the data and the potential for error could engender more pilot trust than is justified. Displays of future potential positions, or a range of future positions, should be considered.

One method of depicting traffic aircraft uncertainty is described by Gempler and Wickens (1998). The traffic aircraft had a straight line predictor showing the intended path. On each side of the straight line were curved lines, producing a wedge shape from the apex of the traffic aircraft symbol, depicting the boundaries of the 95% confidence interval. The wedge indicated that the future position of the traffic aircraft was relatively certain in the near future, but uncertainty increased as the time to the predicted future location increased. The predictors were not 100% reliable. The display was a 2-D coplanar display with a top-down and forward-looking view. An example of a similar display of the top-down view is shown in Figure 5-1.

In all, the wedge indication did not mitigate the effects of predictor unreliability. Results of the Gempler and Wickens (1998) study indicated pilots appeared to be overly dependent on the automation, regardless of reliability. Time spent in conflict for both the straight line and wedge conditions was small, but the wedge condition did impact the amount of average time spent in conflict: 2 seconds/trial for the straight line and 4 seconds/trial for the wedge. As compared to straight line condition, the wedge shape appeared to induce pilots to lateral maneuvers, which were not always the best options for safety in the conflicts tested. Two explanations were offered for these results. First, the additional clutter added by the wedge may have compromised other benefits that the display had to offer. Second, the pilots using the wedge shape indicator did not use the wedge to calibrate uncertainty, but it did appear to induce shift to the preference of lateral maneuvers. Lateral maneuvers tend to be slower than vertical maneuvers, thus resulting in a longer time in conflict.

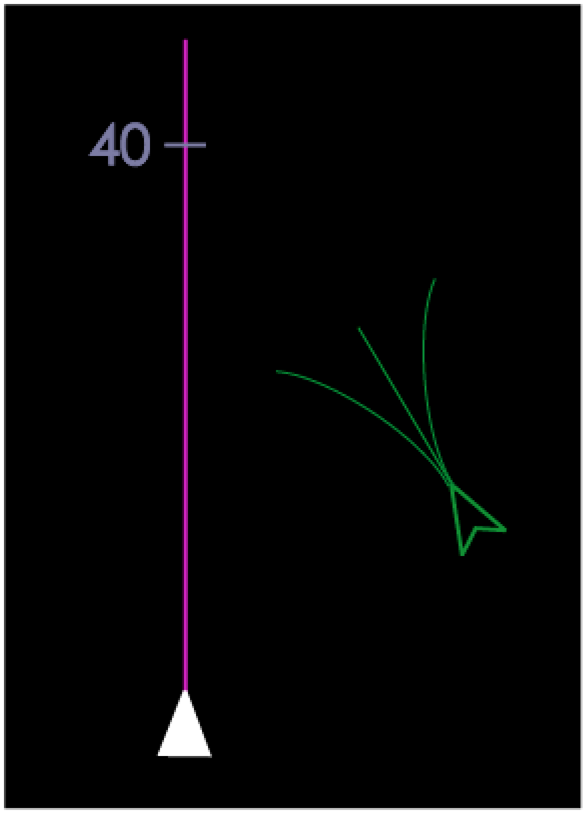

Figure 5-1. Traffic Aircraft Future Position Uncertainty

Recommended Indication of Future Position Uncertainty – The example in Figure 5-1 may be acceptable for displays with few aircraft, but the display will become cluttered if several aircraft are presented. Some method for indicating the uncertainty of traffic aircraft location should be developed to provide a clear indication of both lateral and vertical location uncertainty without resulting in excessive clutter. Pilots may desire the capability to view a most likely position (the straight line in Figure 5-1), and have the option to toggle on and off the uncertainty indications (the curved lines in Figure 5-1). *The exact nature of position uncertainty indication requires further research.* Regardless of the nature of the indication of position uncertainty on the display, any conflict detection algorithm should consider position uncertainty in its alerting calculations (see Section 7.2, Airborne Conflict Management, for a discussion of this issue).

Automation Awareness: Properly constructed automation will build the pilots' confidence and trust in the system. They know that the system is programmed to select the most efficient runway, for example (Orlady, 2000). However, with this trust may come complacency (Parasuraman, Molloy, & Singh, 1993), and pilots may not be motivated to explore more beneficial options, or question the basis on which 'the system' has made an input. They also may not check up on the automation to the extent necessary. This effect may be seen in three of the early Airbus A320 accidents, where highly experienced pilots apparently lost awareness of such fundamental aspects of the flight path as airspeed, vertical speed, altitude, and energy.

Conversely, Riley (1996) has demonstrated significant individual differences in pilot trust in automation, including documenting cases where nearly half the pilots in two experiments allowed faulty automation to continue operating without intervention despite obvious performance degradation. The potential for complacency is another reason that automation outputs such as future position predictions should not imply more accuracy and precision than is warranted.

Recommendations to Improve Automation Awareness – Automation should be implemented to enhance situational awareness and behave in a manner consistent with pilot expectations. *The exact nature of these requirements and methods for implementing automation awareness require further research*. These determinations should be made on an individual basis for different automation implementations.

Mode Surprises

If a pilot makes a change to a parameter, logical changes should be made to related parameters, or at best, no unexpected parameters should be altered. For example, it is not unexpected for a pilot to input an expected crossing altitude for a busy arrival. In the Airbus A-320, all of the programmed crossing altitudes drop out if a new runway is selected by the pilot (Orlady, 2000).

Furthermore, the logic used to determine intent will need to vary from aircraft type to aircraft type due to differences in mode logic. For example, some aircraft will not violate the altitude dialed into the autopilot glareshield altitude window. Therefore, the glareshield altitude should be considered an altitude constraint, and an aircraft in vertical speed mode approaching a target altitude should be predicted to capture that altitude. However, this logic does not apply to the MD-80 aircraft; in that series, a vertical speed adjustment during climb or descent will clear the target altitude because the vertical speed mode does not respect an altitude target. Since pilots can only be expected to be familiar with their own aircraft type and its mode logic, intent statements must be mode-independent; they should indicate the future trajectory of the aircraft using criteria specific to individual aircraft types, with outputs that are standardized across aircraft types. (In the MD-80 example, the intent statement should not indicate a target altitude and a rate of climb if the aircraft is in a vertical speed mode and will not capture that altitude. Instead, it should indicate rate of climb and that no target altitude is set. However, target altitude and rate of climb may be appropriate for a B-777 in the same mode and on the same trajectory.)

Ensure that if a procedure is done one way in one mode, that it is done the same way in all modes (Mejdal et al., 2001). Although pilots may become quickly proficient in certain programming tasks, they may not always respond correctly in unexpected situations resulting from the automation. Furthermore, the need for pilots to be aware of the future trajectories of surrounding aircraft, and the dependency of those trajectories on aircraft modes, may extend the potential for mode surprises beyond the bounds of one's own aircraft to all the other aircraft in the vicinity. Due to the nature of such surprises, such responses are not easily learned. Some researchers have suggested using part-task trainers to allow pilots time to "free play" to investigate system responses to various inputs (Orlady, 2000).

5.3.2 Voice Input

The field of speech recognition has matured over the years and speech command is expected to become a common method of control and input (Mejdal, et al., 2001). Using voice input rather than manual input can reduce the amount of heads down time on the FD. Mejal, et al. 2001 recommended the following guidelines in the implementation of voice input:

- Use voice command technology for the immediate selection of a particular item that may not be currently on the displayed level.

- Ensure that the voice recognition rate is at least 98% accurate.
- Immediate feedback should be provided to minimize any confusion to the user.
- The voice controls are supplemental to the traditional manual methods.
- A correction or 'undo' capability must be provided to reduce the consequences of recognition errors.

Within the DAG-TM framework, voice input may have application in selecting traffic aircraft, streamlining the process of drilling down through menus, selecting desired display pages, and changing display parameters (e.g., display range).

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6. BASIC DISPLAY FEATURES

A number of display features are common to both en route and terminal arrival tasks. These features include airspace constraints, route information and aircraft information (ownship and traffic). Information requirements for these basic features are presented in Table 1 (see Appendix).

6.1 AIRSPACE CONSTRAINTS

Three types of airspace constraints have been identified in relation to DAG-TM: special use airspace, weather hazards, and terrain features. Methods are described for presenting each of these constraints on the CSD.

6.1.1 Special Use Airspace

Special Use Airspace Location: Special Use Airspace (SUA) should be indicated on the ND to indicate locations into which the pilot should not fly, or take caution when flying into them. The pilot will need to know what kind of restrictions are placed on the airspace, and whether it is currently in use. At-a-glance information should be available to indicate the types of restrictions associated with the airspace (high/low altitude use, visual flight rules (VFR)/instrument flight rules (IFR), continuous, etc.).

Color/Fill Pattern: An indication is needed to distinguish between different types of SUAs:

Prohibited (P)	Warning (W)
Alert (A)	Restricted (R)
Military Operations Area (MOA)	

Ideally, the type of restriction placed on the airspace should be immediately apparent from the color/pattern coding used. Colors selected to indicate SUAs should be distinguishable from those used to indicate weather. However, overuse of color coding should be avoided to minimize visual clutter. When colors are used to assign unique meanings, no more than six colors should be used (Doc 9758-AN/966, 2000).

Current Color Conventions:

Blue – Used to indicate prohibited, alert, warning, and restricted areas on IFR En Route Low Altitude charts and Sectional Aeronautical charts.

Magenta – Used to indicate MOAs on Sectional Aeronautical charts.

Brown – Used to indicate MOAs on IFR En Route Low Altitude charts. Note that brown may not have high enough contrast to be easily discriminated on the black screen.

Current Fill Pattern Conventions: To minimize the number of colors required to indicate SUAs, different types of fill patterns (cross hatches, stripes, etc.) may be employed to differentiate the various SUAs. Examples of these coding methods are shown in Figure 6-1.

Horizontal and vertical cross hatched border – Used to indicate P, A, W, and R areas on IFR En Route Low Altitude charts and Sectional Aeronautical charts. Also used to indicate MOAs on IFR En Route Low Altitude charts.

Diagonal cross-hatch border – Used to indicate Special Airport Traffic Areas on Sectional Aeronautical charts.

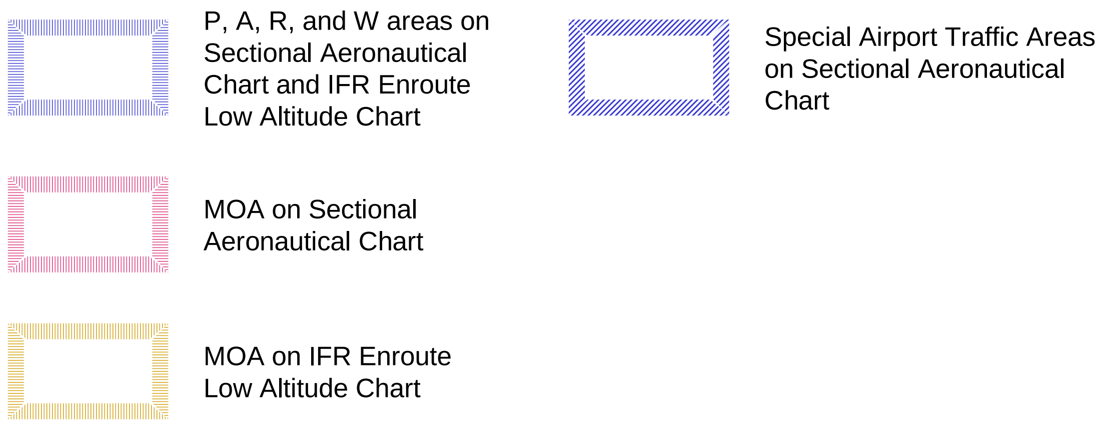


Figure 6-1. SUA Indications

Recommended SUA Color and Fill Pattern – Use colors and fill patterns representative of color and pattern conventions used on Sectional Aeronautical and IFR En Route Low Latitude charts. For example, blue with horizontal or vertical cross hatches to indicate prohibited, alert, warning, and restricted areas. Although the paper charts use colored and patterned *borders* only to indicate SUAs, it may be necessary to fill the entire SUA on the electronic display – if a pilot has selected to display a small range (i.e., zoomed in), it is possible that only a small section of the border would be apparent, or none at all would be apparent if ownship is within the SUA. A type of crosshatch fill pattern resembling those currently used may be acceptable, as they provide an indication of the area, yet allow other information layered beneath it to be seen (e.g., weather). The crosshatches may be color coded using the color conventions on IFR En Route Low Altitude charts and Sectional Aeronautical charts. Such crosshatching could be used to indicate other 'no-go' areas, such as terminal arrival convective weather (Section 9.2.1.1) and approach zone boundaries (Section 9.2.1.2). However, large patterned and colored areas may be distracting and impair the readability of overlaying text and symbology. If a fill pattern is used, the width and spacing of the lines must be considered to ensure compatibility with other display elements (see Figure 6-2). *The exact method for indicating these areas must still be researched.* An alternative approach is to use a single equivalent color and fill pattern for multiple SUA categories with a text label to differentiate them (as noted, Warning, Restricted, Prohibited, Alert areas have equivalent markings on Sectional Charts and are used with a text label).

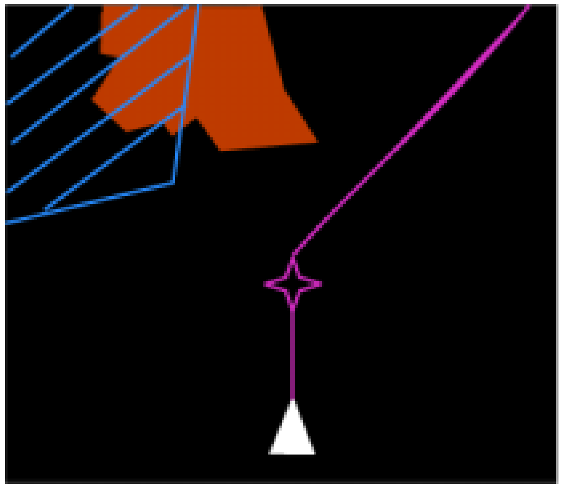


Figure 6-2. SUA and Weather Displayed

SUA Status – For SUAs that are not continuously in use, pilots will need to be able to determine the current and (near) future status of the airspace. Pilots should have the capability to receive data on the airspace status, either via datalink or voice communication.

6.1.2 Forecast Weather

Timeliness: Pilots need to have current weather information. If pilots are to have accurate SA, displayed information must be time-coherent at less than one second and not be older than five seconds (van Gent, et al., 2000). For weather-specific information, a five minute update rate of graphical weather information was acceptable for general aviation (GA) pilots in strategic planning, but a faster update rate is necessary for tactical planning (Latorella & Chamberlain, in press). In the absence of current weather information, studies have shown that pilots tend to respond to weather data as if they are current, even if they are aware that they are not (Latorella & Chamberlain, in press; Yuchnovicz, Burgess, Heck, Novacek, & Stokes, 2000). It is therefore imperative that pilots have current data available, and if the data are not current, pilots need to be aware of how old the data are.

Recommended Weather Information Update Rate – Weather data should be real-time, or as close to real-time as possible. If data are not real-time, pilots must be aware of the age of the weather information. Pilots using aged data to make decisions may inadvertently fly into hazardous weather or miss the opportunity to fly through dissipated weather cells.

Forecast Weather**:** Pilots have two requirements for weather information, tactical and strategic. These two requirements have explicit planning horizons. In the case of tactical planning, pilots need to know the tops and bottoms of existing weather cells that they can see out of the windscreen. In terms of strategic planning, pilots need to know frontal movement, convective weather conditions, etc. along their planned route. These two different requirements imply the need for both airborne weather radar that conveys current situations and a weather information system that portrays future problems along the planned route.

Pilots need accurate forecasted weather information (Novacek, Burgess, Heck, & Stokes, 2001). A problem arises in that current weather forecasting technology cannot provide long-term, accurate information. Generally, the farther out the forecast is, the less accurate it is. Thus, a trade-off exists between providing pilots with no data at all on weather forecasts, and providing data that are less than 100% accurate.

Recommended Weather Forecast Formats – One solution may be to provide forecasted data, but include information on the accuracy of the data. For example, there is a 75% chance that a weather cell will develop and move in some direction within the next 80 minutes. *Research is needed to identify which methods should be implemented to show future weather indications combined with information on the accuracy of the data.* In any case, the weather information must provide an unambiguous indication as to whether the data are *current*, or *forecast*, so that pilots do not become confused over the actual state of the data. Errors can result if a pilot attempts to make tactical decisions based, for example, on a 90 minute forecast.

Levels of Weather Severity: A hierarchy exists for flight plan optimization. This hierarchy is comprised of factors that result in pilot- or AOC dispatcher-initiated route changes, such as safety, legality, company policy, efficiency, and comfort in order of importance. The decision of whether to go through a weather hazard quite often depends on numerous additional aspects such as time of day, aircraft type, and overall schedule delays. The need to balance pros and cons of going through a hazard implies the requirement for multi-level hazard descriptors. Weather hazards are amenable to level descriptors by nature of their effect on the operation. Quite often weather hazards are described with an associated severity index, e.g., severe icing. To determine the appropriate number of levels needed to describe a particular hazard, hazard type was plotted against factors leading a pilot or dispatcher to route around or through a hazard. The Figure 6-3 summarizes the results (Honeywell, 1999).

WX Hazard	Comfort	Efficiency	Company Policy	Legality	Safety	No. of Levels
Convection		×	×		×	3
Turbulence	×	×	×		×	4
Icing			×	×	×	3

Figure 6-3. Hazard Levels

Different levels of weather hazards, and methods currently used to depict these levels on pilot displays, are described below.

Turbulence: There are at least two existing color conventions currently in use to indicate turbulence:

Color	System
White	MD-11
Magenta	Honeywell RDR-4B weather radar

Figure 6-4. Color Coding of Turbulence

Convective Weather: There are at least two color conventions currently in use to indicate severity of weather. Current color coding based on intensity of onboard weather radar return includes is described below.

Color	System	Meaning
Magenta	MD-11	Precipitation greater than 50 mm/hour
Red	MD-11	Warning – precipitation 12 to 50 mm/hour
Red	RDR-4B	Precipitation greater than 12 mm/hour
Amber	MD-11	Caution - precipitation 4 to 12 mm/hour
Amber	RDR-4B	Precipitation 4 to 12 mm/hour
Green	MD-11	Information - precipitation 1 to 4 mm/hour
Green	RDR-4B	Precipitation 0.7 to 4 mm/hour

Figure 6-5. Color Coding to Indicate Weather Severity

Multiple colors in the conventional weather radar display permit the pilot to visualize and track the dynamic changes in convective weather. Using the full range of color coding allows the pilot to recognize developing thunderstorm cells that may soon require a request for rerouting. If only one or two colors are used to indicate impassable weather, it will be more difficult for the pilot to interpret these changes. Depending on the threshold for displaying the caution or no-go areas, the colored areas may not be present long enough to signal to the pilot that there is a larger area where new cells may emerge (S. Metz, personal communication, April 29, 2002).

Recommended Use of Color to Indicate Weather – Because the overuse of color causes visual clutter, it is not recommended that all four levels of color be used. It is possible that a pilot does not need to know all the details of current or developing weather situations. Instead, a pilot may need only to know if he can fly through the weather or go around it. Using one or two colors to depict caution or no-go areas can be effective. *The appropriate amount of color coding that is adequate for DAG operational concepts is an issue that requires further research.*

Wind: Conventional wind indicators include information of wind speed and direction. Use of conventional wind indicators is appropriate for the CSD. Wind barbs, shown in Figure 6-6, are one such conventional wind indicator. The flags show the velocity of the wind with pennants and tick marks.

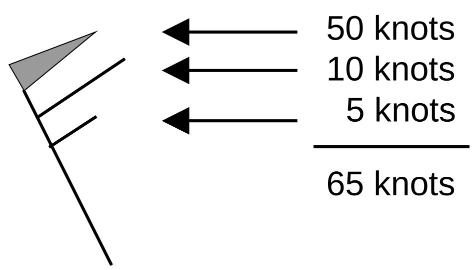
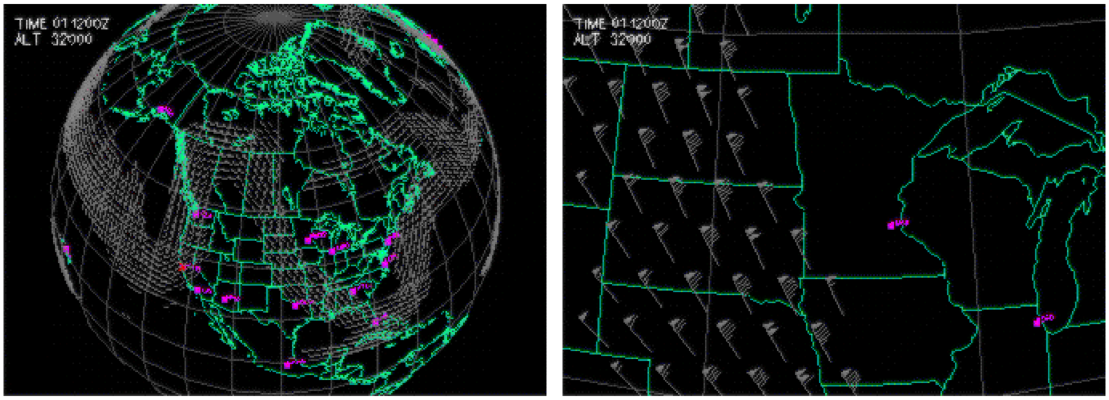


Figure 6-6. Wind Barbs

In the example shown above, the pennants are each worth 50 knots, long tick marks are worth 10 knots, and short tick marks are worth 5 knots. The total wind speed is the sum of the pennants and tick marks. The wind blows from the pennant in the direction that the shaft points.

In the example, the wind is blowing towards the southeast. Figure 6-7 shows how multiple wind barbs may be used to indicate large areas of air movement. To reduce clutter on the displays, there needs to be a way for the pilot to remove the wind barbs if not needed.



(a) (b)

Figure 6-7. Aviation Weather Information (AWIN) World View (a) with Wind Display and Details of the Weather Display (b)

However, decision aids in the form of simple graphics or icons are probably not very useful in this environment (Lindholm, 1999). Although the wind barbs may be useful in giving a global indication of wind (as in Figure 6-7), more detailed and at-a-glance information may be required in tactical situations.

Recommended Wind Indication – The wind barbs described above provide icons to allow the pilot to determine the location and strength of wind. Such indications are appropriate for gross estimates of wind conditions. In Figure 6-7(a), the pilot can instantly determine the general pattern of the jet stream. By assessing the approximate number of pennants and tick marks on the barbs, the pilot can get an idea of prevailing winds for strategic planning. However, such indications of wind may not be appropriate in tactical, localized decision-making in the event of thunderstorms or in the terminal area. Current, at-a-glance graphical information should be provided. *The exact nature of this graphical indication is an area of research.*

6.1.3 Terrain

The advent of the Enhanced Ground Proximity Warning System (EGPWS) and incorporation of its symbology onto the navigation display has raised significant formatting issues for today's display designers. Both conventional weather and terrain formats use color to depict levels of hazard, and because FD color conventions are relatively restrictive, both types of display have tended to use the same color set. This repeated use of the same color sets for different airspace hazards can result in confusion. A pilot may not know if 'yellow' is indicating a weather hazard or a terrain hazard, which is significant because the two conditions require different responses. Alternative methods must be developed to effectively depict the exact nature of the airspace hazard.

6.1.4 Abstraction of Airspace Hazard Information

Integration of terrain and weather data on the same display requires that the two types of hazard be disambiguated. When SUA and traffic hazards are added, there is a high potential for overloading the display. When several types of hazard share the same color codes, they must be distinguished by other means, such as texture. But the fact remains that too many hazard types on a single display can lead to too much information and clutter on the display.

Weather information should be transformed into visualizations and decision aids that facilitate direct inferences and immediate action by the pilot (Lindholm, 1999). One possible approach would be to integrate the hazard information into higher-level categories, such as “prohibited”, “restricted”, and “unrestricted”. In this concept, terrain, convective weather above a certain level of intensity, certain types of SUA, and certain traffic constraints that the pilot cannot penetrate under any circumstance would be depicted as red. Weather that might be uncomfortable to penetrate but not hazardous, a SUA that does not involve safety threats, and terrain below the aircraft but not immediately threatening might be depicted as yellow, indicating that the pilot can penetrate those areas if necessary. This “no go” (red) and “may go” (yellow) abstraction of the more detailed threats might give pilots a more useful and usable depiction, supporting their basic decision needs (“can I turn here or not?”). Of course, pilots should still be able to call up more detailed information to see the nature of the threat at any time. Given the tendency to put all lateral situation data on the navigation display and the plan to add traffic and SUA information to the existing terrain and weather depictions, this type of abstraction may become a necessity if the display is to be readable and usable.

One such approach taken by Honeywell researchers involved presenting pilots with 4-dimentional hazard polygons with associated severity levels (Honeywell, 1999). Pilots choose thresholds that they are comfortable flying through and can plan routes accordingly. For example, the pilot may be willing to accept a route through occasional turbulence if it results in appreciable fuel and time savings. An example of the proposed system is illustrated in Figure 6-8. Pilots are able to visualize their flight path with the corresponding hazards in both lateral and vertical views. Pilots would be able to easily de-clutter the display by choosing which type hazards they wanted displayed. The modeled hazards in this case move with time and the system allows the pilots to do “what-if” projections.

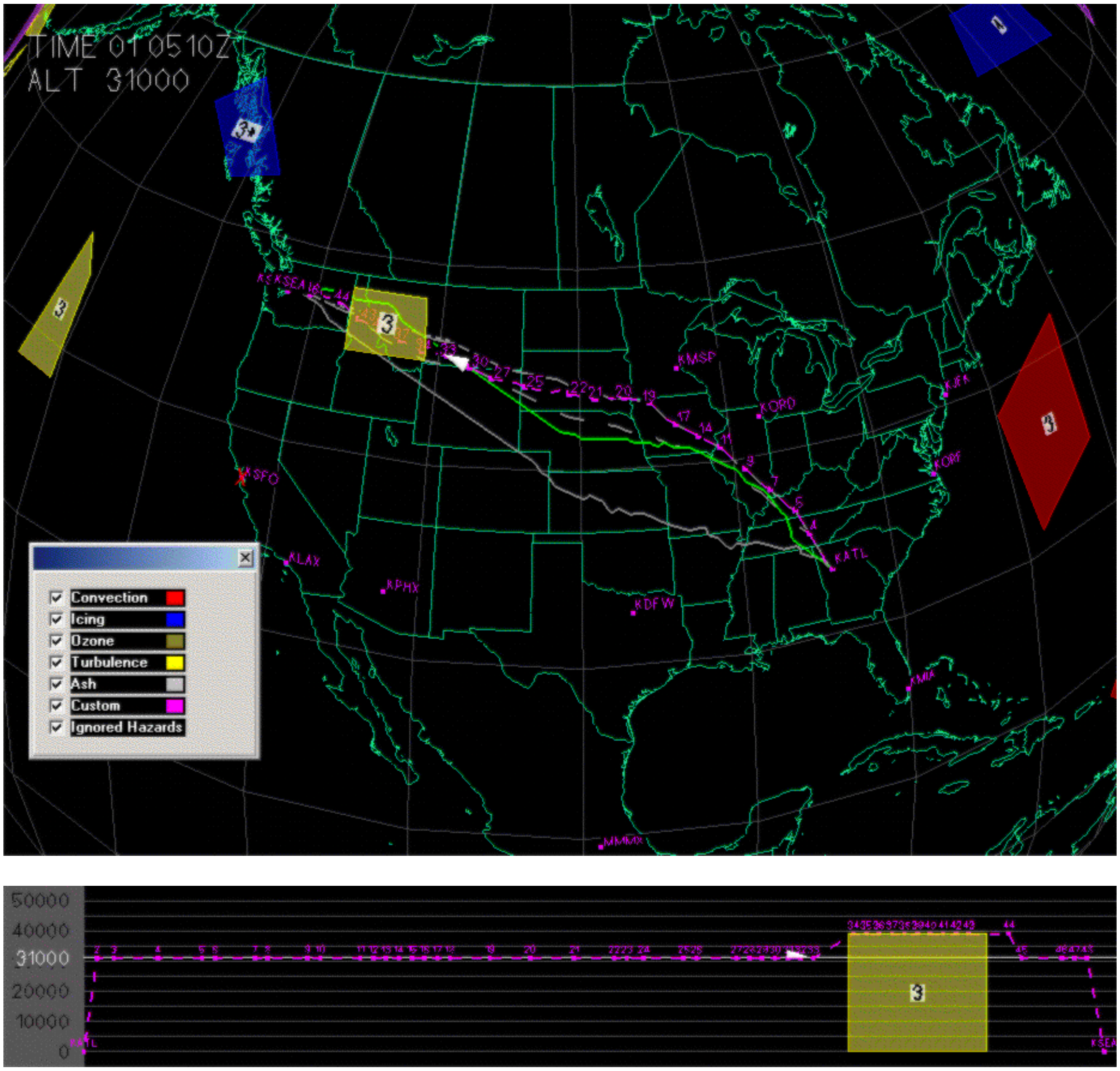


Figure 6-8. AWIN Display of Route and Weather Hazards

If such abstractions of airspace hazards are to be implemented, it is critical that pilot information needs are assessed in detail. It will be the designer's job to ensure that the data are properly assimilated into a form that is usable for pilots. The level of each type of hazard (weather, terrain, SUA) must be quantified so that it falls into the appropriate hazard category (Level 3 or 4 as shown in Figure 6-8). Researchers must determine exactly which levels and types of weather constitute "no go" areas, and which constitute "may go" areas. Pilots should not be surprised by the conditions they encounter if they enter a "may go" area.

Recommendations for Airspace Constraints – The merits and drawbacks of using individual constraints indications (e.g., type and level of weather, SUAs, terrain) vs. abstractions require additional research.

6.2 ROUTE INFORMATION

Route information should be available to the pilot at all points during flight from takeoff to the terminal area. This section addresses only waypoints during free maneuvering. Terminal area maneuvering is a special case which is addressed in Section 9.2.

6.2.1 Waypoint

Waypoints indicate a specific point on a route. Waypoints may be fixed points (e.g., specific latitude/longitude) or conditional (e.g., when reaching a specific altitude) (Honeywell, 1996).

Waypoint Symbol: The symbol should be easily discernable from background clutter, for example:

Four Pointed Star – Domestic standard symbol used to indicate waypoints.

Diamond – European standard symbol used to indicate waypoints.

Triangle – off route waypoint

Waypoint Coding: Active waypoints (the one towards which the pilot is flying), and non-current (passed, future) waypoints are distinguished by color. Current color coding conventions include:

Current waypoint –

Magenta (MD-11, B747-400)

Inactive (future/past) waypoint –

White (MD-11, B747-400)

Off route waypoint -

Blue (B747-400)

In order to avoid over use of color, waypoints can be coded using either a highlighting or intensity technique. For *highlighting*, the current or active waypoint is depicted as a bold (increased line thickness) symbol while future waypoints maintain a standard line thickness. The domestic standard symbol convention is shown in Figure 6-9. It is highlighted, in contrast to the standard depiction used for the future waypoints.

Figure 6-9. Waypoint Symbology with Highlighting

For *intensity coding*, shown in Figure 6-10, a current waypoint is represented as a symbol with higher color intensity than future waypoints while line thickness is held constant. In both intensity coding and highlighting, a single color or hue is used.

Figure 6-10. Waypoint Symbology with Intensity Coding

Recommended Waypoint Symbology – To minimize changes in conventional display symbology, the current domestic standard waypoint symbol – four pointed star – is recommended. Color coding should be consistent with current practice, which differs from manufacturer to manufacturer. Some manufacturers use magenta to indicate that the FMS is the source of the data (a magenta waypoint in this scheme indicates that the waypoint is in the FMS-commanded flight path). Others use magenta to indicate the currently active flight path target, regardless of the source (in this scheme, a magenta waypoint is the next one in the flight plan, and the aircraft is in LNAV mode). Color conventions for other display features should be consistent with whatever color code is adopted by the manufacturer.

6.2.2 Required Time of Arrival

Currently, a required time of arrival (RTA) is a waypoint with a time associated with it. RTAs indicate locations that a pilot must reach at a specific time. RTAs may be a single point in space, an area (such as an arc around a location - for example, an arc fixed at a specific distance from an arrival zone boundary) or a three-dimensional area in space.

Recommended RTA Symbology – If RTAs are a single point, they may be represented the same way that waypoints are represented. If a RTA is defined as a plane or area, different methods of implementation must be created. In any case, an indication of the arrival time should be provided. An indication of relative time to arrival could be useful, so that the pilot knows if he should speed up or slow down to reach the RTA. This indication of relative time of arrival could show the predicted time of arrival alongside the current RTA (to allow comparison) or a single value that is the difference between the predicted and required time of arrival. *Implementation of RTAs in the future is still an open issue that requires further research.*

6.3 AIRCRAFT INFORMATION

6.3.1 Ownship

Pilots must know the exact position of ownship. They also need to know the location of traffic aircraft, and also the current position, heading, speed, and altitude. It is also desirable to have information on future position (extrapolated from current state, or intent data).

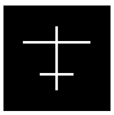
Ownship Symbol: Ownship should have a distinct symbol which is easily discriminated from background features and other symbology. Some examples of current symbology are shown in Figure 6-11. The use of the “simple aircraft silhouette” is more ecologically valid because in reality the ownship is nearer to the flight crew and hence more detailed, while the other traffic is farther distant and is naturally less detailed. Therefore this choice reinforces the correct perspective (S. Metz, personal communication, April 29, 2002).

Ownship Color:

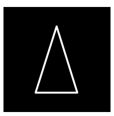
White – TCAS, MD-11, NASA Ames (AILS), NASA Langley (Advanced Terminal Area Approach Spacing (ATAAS), Airborne Use of Traffic Intent Information (AUTRII))

Cyan – TCAS

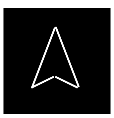
Recommended Ownship Symbology – A distinct, easily discriminated symbol should be used to indicate ownship, such as the simple line drawing or silhouette shown in Figure 6-11. Ownship should be shown in white.



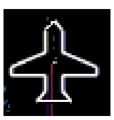
Simple line drawing
(TCAS (FAA, 2000a), NLR (NLR, 2000))



Arrow head
(TCAS (FAA, 2000a), NASA Langley AILS (Abbott & Elliott, 2001) & ATAAS)



Chevron
(NASA Ames AILS (Comerford & Uhlarik))



Simple aircraft silhouette
(NASA Langley AUTRII).

Figure 6-11. Examples of Ownship Symbology

6.3.2 Traffic Aircraft Symbol

Symbols should be easily discernable from background clutter, with at-a-glance indications of heading and relative altitude. It is desirable to have heading information integrated into the symbol, so that a separate indication is not necessary (e.g., line extending from the symbol, such as that used for the circle, diamond, or square in Figure 6-12). Symbols that have been used are shown in Figure 6-12.

Circle - Used in TCAS – Requires a line to indicate

Diamond - Used in TCAS - Requires a line to indicate

Square - Used in TCAS - Requires a line to indicate

Wedge - Apex of symbol indicates aircraft

Chevron - Apex of symbol indicates aircraft

Figure 6-12. Examples of Traffic Aircraft Symbols

Recommended Traffic Aircraft Symbol – A simple shape with integrated heading indication, such as a wedge or chevron is recommended for presenting traffic aircraft position. If the traffic symbol used is other than TCAS, then the shape change in the collision avoidance situation provides an additional cue to the urgency of the situation. It should be noted, however, that studies indicate that continuity must exist between CSD symbology and existing TCAS symbology (van Gent, et al., 2000).

Actual Aircraft Position: Depending on the display range the pilot has selected, the aircraft symbols on the display will not accurately reflect the size, and therefore location, of the actual aircraft. For example, if all features in the environment were scaled to the appropriate size at a displayed range of 640 mi, the actual aircraft would be just a small pixel grouping on the display. To aid visibility of the aircraft on the display, the symbols are depicted in a standard size for all display ranges, and the symbols used to depict traffic and ownship are much larger than the actual aircraft at extended ranges. It is therefore critical for the pilot to know what part of the symbol indicates the actual aircraft location.

For some shapes (circle, diamond), actual aircraft position is the center of the symbol. However, this implementation requires the pilot to make judgment on the location of the center. Other shapes (wedge, chevron) have distinguishing features that can indicate the actual aircraft position (e.g., the apex). Current actual aircraft position is represented at the apex of the ownship symbol on the B-777 (B-777 FMS implementation, Section 2.8.8, p. 2-46) and this is also the recommended methodology in ARP 5365 (SAE, 2000).

Recommended Method – Since the wedge or chevron shape is recommended, it is further recommended that actual aircraft position correspond to the apex of the symbol. If information for traffic is similar to ownship (e.g., actual aircraft location), the implementation method should be the same for both classes of aircraft. For example, actual aircraft position should be at the apex of both ownship and traffic symbols – it should not be the center of one symbol (e.g., ownship symbol) and at the apex of another (e.g., traffic symbol).

6.3.3 Out of Range Traffic Symbol

It is possible that traffic aircraft causing an alert may not be present on the display due to the range selected – it is out of range. If a pilot receives an alert pertaining to an aircraft that is not displayed on the screen, he or she could become confused. Therefore, it will be necessary to indicate the location of the traffic on the display. Few methods for implementing out-of-range traffic have been studied. One such method uses a half-symbol (half of the aircraft symbol) shown at the edge of the display with an indication of current heading (e.g., TCAS II).

Recommended Out of Range Traffic Symbol – It is recommended that some sort of indication be presented to indicate out of range traffic. Because clutter will most likely be a problem on a CSD and available space is limited, f*urther research is required to determine what method is most appropriate to indicate out of range traffic.*

6.3.4 Managed vs. Autonomous Traffic Symbols

Knowledge of whether or not aircraft are equipped for free maneuvering is necessary. This information will tell the flight crew which aircraft have the authority to modify their flight paths and which are under the guidance of ATSPs. It also informs the flight crew as to which aircraft can "see" them and are required to follow the SOPs for self-separating aircraft.

One method to distinguish between free maneuvering and managed aircraft that has been implemented in tests (Adams, Helbing, Duley, & Legan, 2001; Mafera, Helbing & Duley, in press) uses a stinger: a short line at the apex of the aircraft symbol to indicate a free maneuvering aircraft. Managed aircraft do not have the line symbol. However, as the concept matures and the majority of aircraft in the future are expected to be free maneuvering, it may be more appropriate to indicate only aircraft that are *not* equipped. Using the logic that only managed aircraft should contain special indications, the symbol described in Adams et al. (2001) and Mafera et al. (in press) should be reversed (see Figure 6-13[a]). This cue provides at-a-glance information that enables pilots to distinguish between the two types of aircraft, yet minimally increases clutter. In addition, the encapsulated stinger symbol on the managed aircraft may suggest that the aircraft is being directed along a vector, or might suggest a handle by which the aircraft can be directed, so that symbol is suited to indicating a managed aircraft, while an empty aircraft symbol would indicate that it is free to maneuver. However, without the characteristic of being projected along the future path, the stinger symbol becomes essentially arbitrary.

One drawback to this method, however, is that if predictor lines are available (see Section 6.3.12, Future Position), the predictor lines obliterate the stinger lines, making the free maneuvering and managed aircraft undistinguishable. A solution is to move the stinger back on the symbol, as shown in Figure 6-13[b].

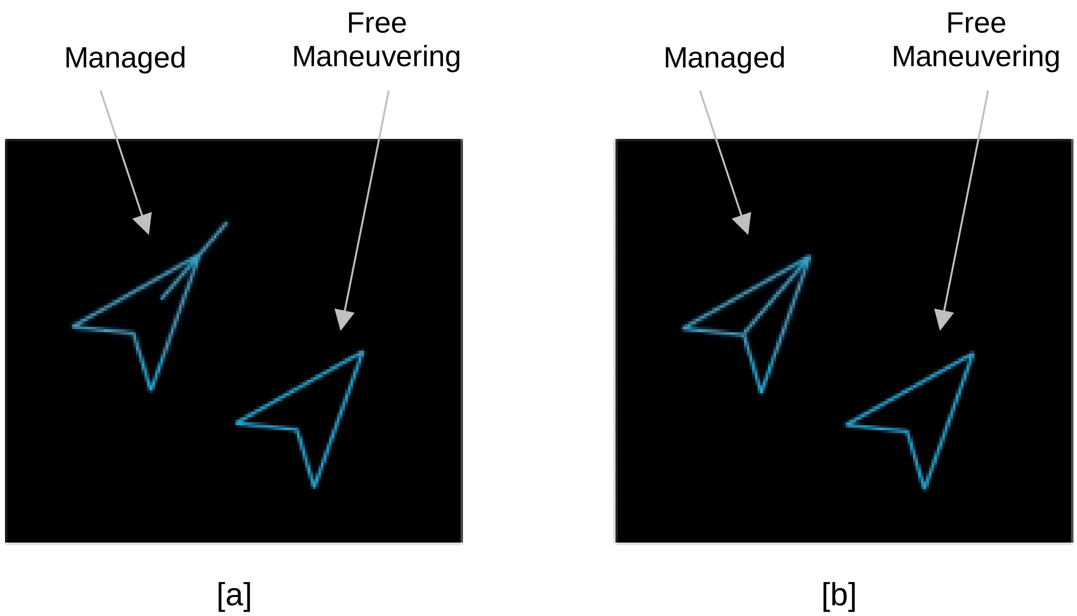


Figure 6-13. Free Maneuvering vs. Managed Aircraft

Another method used in ATC tasks places a frame around the call sign to indicate free maneuvering aircraft (see Figure 6-19). In conjunction with this coding, color coding distinguishes between free maneuvering aircraft that have logged on, and those that have not logged on (Doc 9758-AN/966, 2000). A drawback to this method is that it requires the data tags for all aircraft to be visible, which increases clutter, and potential overuse of color as a coding mechanism.

Recommended Method for Distinguishing Managed and Free Maneuvering Aircraft – None of the solutions provided above are optimal. Other options, such as using filled and unfilled symbols, are often used for encoding higher priority information, and may therefore not be implemented. The type of coding used to distinguish between free maneuvering and managed aircraft is also dependent upon on the symbology that is ultimately selected to depict traffic. *Further research is necessary to determine first if this information is necessary for the flight crew. Second, research is necessary to determine the most appropriate method to distinguish between managed and free maneuvering aircraft on the display.*

Partial Equipage: As some aircraft may be only partially equipped for free flight, it is possible that additional levels of coding will be required to indicate different levels of equipage. This may be particularly relevant for smaller aircraft, or during the time that aircraft are first being retrofitted for free flight capability. For example, an aircraft may have ADS-B and CSD, but no CD&R capability. Or, an aircraft may be able to broadcast, but not receive information from other aircraft. This form of coding will be dependent upon the standards placed upon aircraft to qualify as free maneuvering – it is unlikely that different coding is required for each permutation of equipage.

Consideration must be given to whether a method must also be devised to indicate a fully equipped aircraft that is currently managed, e.g., the aircraft has lost one or more pieces of equipment to enable free flight, or free flight was cancelled. An alternative to devising several levels of coding to distinguish these 'free flight-disabled' aircraft from fully equipped and partially equipped aircraft is to simply include them in the unequipped category until the situation is resolved.

6.3.5 Traffic Aircraft Color

A number of conventions have been applied to traffic color. Often, these methods employ some sort of color coding.

Threat Status Coding – Potential threat level, that is, whether or not a traffic aircraft poses any likely threat to ownship, may be coded. For example, traffic that is above ownship and is climbing most likely poses little risk of conflict in the near future. Aircraft that are far away from ownship and are flying in the opposite direction also pose little threat. These aircraft could be shown in one color, while those that have the potential for coming into conflict with ownship could be a different color. Alternatively, time to conflict may be coded.

TCAS uses color and shape coding to indicate the threat status of traffic aircraft. This section will focus on color coding only. See Section 6.2.2, Traffic Aircraft Symbology, for a discussion of traffic symbology. The information presented below is based on *Introduction to TCAS II* (FAA, 2000a).

Cyan, unfilled – Non-threat traffic

White, unfilled – Non-threat traffic

Cyan, filled – Non-threat traffic, within 6 nmi and ±1200 ft from ownship

White, filled – Non-threat traffic, within 6 nmi and ±1200 ft from ownship

Amber, filled – aircraft caused traffic advisory to be issued

Red, filled – aircraft caused resolution advisory to be issued.

Altitude Color Coding – It is important for pilots to quickly be able to determine the altitudes of traffic aircraft. Although numeric indications of both absolute and relative altitude may be provided (see Section 6.3.7), cognitive processing is required to make a judgment concerning which aircraft are above or below ownship. Because traffic altitude relative to ownship is primary information, it must be available at-a-glance and require little cognitive processing. Color coding may be used as a *redundant* cue in addition to numerical indications of traffic altitude. Mejdal et al. (2001) suggest that, if color coding pertains to altitude, it should depend on the altitude in relationship to ownship, not the ground. In this case, color coding of traffic aircraft can provide an instant indication of the altitude of traffic relative to ownship. Results of a previous study indicate that pilots suggested using three colors to code traffic aircraft by altitude (van Gent, et al., 2000). However, these pilots also stated that strict adherence to color convention and standards was necessary. (Note: Specific information pertaining to color usage and selection may be found in DOT/FAA/AR-99/52, 1999.).

Static Color Coding Example

- Same Altitude – May be shown in the same color as ownship. "Same" altitude may imply a range of altitudes around ownship (e.g., ±1000 ft.), not just the exact altitude as ownship. The range of altitude above and below ownship that is represented by same altitude must be clearly defined so that pilots know what to expect. If a pilot's previous experience with "same altitude" was ±1000 ft, it could be detrimental if the meaning of "same altitude" changed to ±500 ft – the pilot would have less clearance than anticipated.
- Above Ownship – Select a color representing sky – blue, for example, or the same color used on the Attitude Direction Indicator (ADI) to indicate sky. Select a color that is distinct from weather, SUA, or other symbols to maximize readability of the symbol.

- Below Ownship – Select a color representing ground – brown or green, for example, or the same color that is used to indicate the ground on the ADI. Select a color that is distinct from weather, SUA, or other symbols to maximize readability of the symbol. If the CSD is used for a surface surveillance application, brown may be reserved for aircraft on the airport surface.

Dynamic Color Coding Example – A method of dynamic color coding was developed and tested, in which traffic aircraft changed color in an integrated display of both relative altitude and vertical trend (Beringer, Allen, Kozak, & Young, 1993). Color coding was used to indicate if traffic was below (brown) or above (blue) ownship, and to indicate relative altitude (0 to 500 ft. = red; 501 to 750 ft = red/yellow; 751 to 1250 ft = yellow; 1251 to 1500 ft = yellow/green; 1501 to 2000 ft = green). Vertical trend was indicated by changing part of the border that was vertically closest to ownship to white (e.g., a descending aircraft that was above ownship would have a white apex and blue tail, as shown in Figure 6-14). Dynamic color coding and a more traditional color coding scheme (similar to the static color coding described above) were compared to the dynamic color coding method. Results of the study indicated that both color coding methods generally resulted in fewer altitude classification errors and faster response times than numeric indications of traffic altitude. However, dynamic color coding did not benefit performance as compared to static color coding (Beringer, et al., 1993).

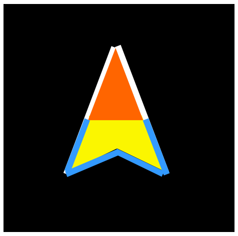


Figure 6-14. Example of Dynamic Color Coding

Recommended Traffic Color – Color coding of traffic aircraft may be implemented as a redundant source of coding in addition to symbol shape and numeric indications of factors such as altitude. Because DAG is a new concept, studies are still being conducted to determine what pieces of information are most critical to pilots completing the tasks associated with the concept. Results of the AUTRII study indicated that pilots were evenly split on their reliance on altitude tail tags vs. color coding for traffic-aircraft altitude information (Wing, et al., 2001). It is likely that some type of static color coding will be implemented, but *the exact nature of the coding is a topic of research*. This research should include investigations of the exact nature of color coding (e.g., static vs. dynamic), and the appropriate levels of relative altitude difference (e.g., ±500 ft or ±1000 ft) that should be encoded.

6.3.6 Traffic Altitude Indication

As discussed above, color coding provides an effective means to indicate traffic aircraft altitude. Although color coding the relative altitudes of traffic aircraft provides at-a-glance information, pilots may require more precise indications of the absolute or relative altitudes of traffic aircraft.

Numeric indication of absolute/relative altitude may be associated with the traffic aircraft. This information may be integrated into the data block, or may be depicted as a separate piece of information.

Tail-Tag Altitude: Tail-tags may be presented at the tail of the aircraft icon indicating relative altitude or absolute altitude. TCAS shows relative altitude in hundreds of feet above (+) or below (-) ownship. The text is above the symbol if the traffic is above ownship, and below the symbol if the traffic is below ownship, as shown in Figure 6-15.

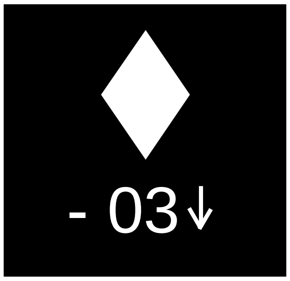


Figure 6-15. TCAS Traffic Symbology – 300 ft Below Ownship and Descending

Figure 6-16 shows another example of the tail tag altitude indications. The location of the tail tags is fixed to the aircraft, so that the tail tags remain at the rear of the aircraft icon. '+' and '-' are placed before the relative altitude, to indicate whether the aircraft is above or below ownship. This allows for distinction between the two states in cases where the aircraft is at the 'same' altitude (e.g., ±1000 ft) as ownship.

The tail tag altitude rotates with the aircraft icon, but is designed to change orientation as the aircraft passes through 90° and 270° of rotation. This precludes the pilot from reading inverted text.

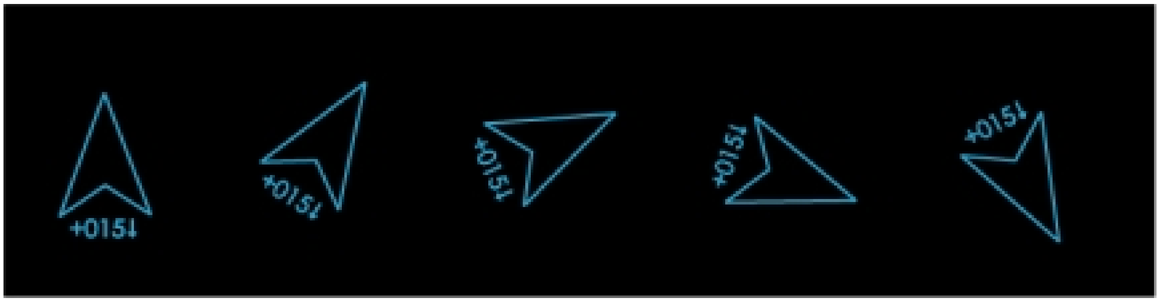


Figure 6-16. Tail Tag Altitude and Vertical Speed Change Indication

Symbol Size Change: Beringer (1991) described a study in which size was used to indicate relative traffic aircraft altitudes. Symbols which are larger than ownship are higher than ownship, and symbols which are smaller than ownship are lower. Size coding provides an indication of the magnitude of difference in altitude.

Recommended Altitude Indications – Color coding appears to be an effective, at-a-glance method for indicating traffic aircraft altitude relative to ownship without adding clutter to the display. *However, whether or not a numeric indication is necessary, or the method in which a numeric display should be presented, requires further research.*

6.3.7 Absolute vs. Relative Altitude Indication

Pilots may want the option to display either absolute or relative traffic aircraft altitudes. A method to change between the two modes must be provided so that the change may be made quickly and with minimal interaction (i.e., few button presses). For example, two buttons may be presented, labeled ABS and REL, which will toggle between the two presentation modes with a single selection on the desired altitude display.

Recommended Absolute vs. Relative Altitude Indication – A method should be provided to allow the pilot to select absolute or relative altitude. Pilots should have the option to display either absolute or relative traffic aircraft altitudes. Pilots could personalize the display to suit their needs, and these settings would be the default. However, there should still be a method provided to allow them to quickly change options during flight. *This feature must be salient so that the two modes cannot be confused. An error consequences analysis may be appropriate to determine the potential for pilots to confuse the two modes.*

6.3.8 Vertical Trend

In addition to traffic aircraft's current altitude, changes in altitude should be indicated. If an aircraft is climbing or descending at a significant rate, an indication should be provided so that the pilot may anticipate the aircraft's future position.

TCAS employs a small up or down arrow next to the relative altitude indication to show the direction of the altitude change if an aircraft is climbing or descending at a rate greater than 600 fpm. The vertical trend arrow is shown in Figure 6-17.

In Figure 6-18, if the traffic aircraft is climbing/descending at a rate exceeding 500 fpm, an arrow is presented next to the tail tag information. The arrow will point up if the aircraft is climbing, and down if the aircraft is descending. Since the tail tag altitude readout rotates with the aircraft symbol, the trend arrow will rotate, also. However, at 90° and 270°, the text and arrow will flip, to preclude pilots reading inverted text.

The dynamic color coding discussed above (see Beringer, et al., 1993) is another alternative to vertical trend indication. However, results of the study indicated that, although color coding was more effective than numeric coding, dynamic color coding (as implemented in that particular study) did not improve performance over static color coding.

Size coding, which was also discussed above, can be used to indicate vertical trend. Beringer (1991) used different sized triangles to indicate whether an aircraft was climbing or descending. For example, if an aircraft was climbing, a small triangle would be connected to a larger dotted triangle with a dotted line, as shown in Figure 6-17. Because of the increased required display space, the use of the concept shown in Figure 6-17 will be problematic on a busy display with multiple aircraft converging on a waypoint or airport. Symbols showing surrounding traffic may obscure each other or make it hard to identify individual symbols from the background clutter.

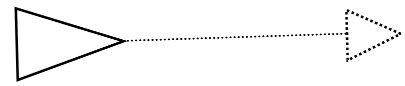


Figure 6-17. Size Coding for Vertical Trend

Recommended Vertical Trend Indication – An indication of vertical trend should be provided. A simple arrow pointing in the direction (up for ascending, down for descending) will suffice. It is critical that the arrow maintain the proper orientation (e.g., that it flips as in Figure 6-16) if it follows the orientation of the aircraft symbol. If the aircraft is in level flight, no arrow should be present. If clutter is a problem, an alternate solution should be researched to indicate vertical trend.

6.3.9 Data Block Information

A number of pieces of information regarding traffic aircraft are necessary in the traditional data block. The call sign, current altitude, and airspeed are usually included in today's displays. With the capability of receiving real-time intent data, it is possible that additional pieces of information may be added to the data block (e.g., target altitude, airspeed, or aircraft type). With all of the information that is available for potential inclusion in the data block, or information that will be required for free maneuvering (e.g., indicating controller pilot data link communications (CPDLC) capability), it is likely that clutter will become an issue. Options for indicating additional information without adding significant clutter to the display (e.g., boxing existing information to indicate some capability) should be explored. Also, users will want the ability to hide/display all or parts of the data block, or to be able to define data block content in order to reduce clutter.

In addition to the traditional information required by pilots during flight, new pieces of information may be integrated into the data tag. There has been some indication from the pilot community that, in addition to the current altitude, they would like to know the intended altitude of climbing or descending aircraft. This information would give them the ability to anticipate potential conflicts. One method of providing this indication is to add the intended altitude to the data block, after the current altitude. A numeric indication could be presented alone, or a graphical indication could be added (Doc 9758-AN/966, 2000), as shown in Figure 6-18. Again, though, this data cannot be derived from the flight plan alone – whether the aircraft will actually capture the stated altitude depends on the selected mode and the mode logic of the specific aircraft.

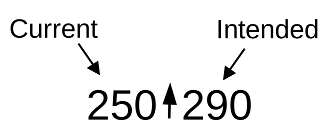


Figure 6-18. Indication of Intended Flight Level

Aircraft type is another item pilots would like to see in the data tag. Pilots require this information when making self-spacing decisions with respect to wake vortices. When all of these items are considered, and unanticipated items are accounted for, data tags can become quite unmanageable (see Figure 6-19). Several suggestions for decluttering data tags are presented as follows:

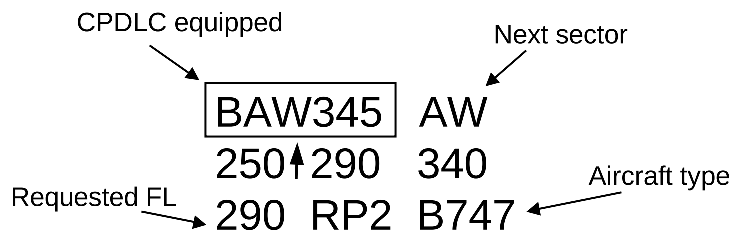


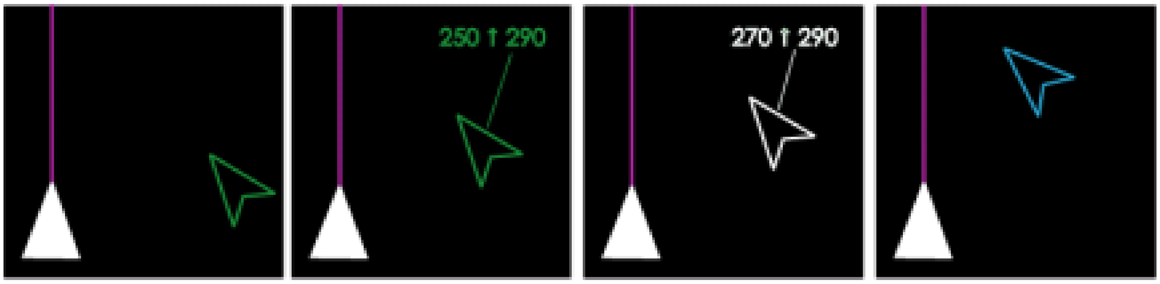
Figure 6-19. Cluttered Data Tag

User Defined Data Tags: Pilots may want the ability to tailor the information in the data blocks to their needs, by selecting the information they would like displayed, and the format of the information. Specific fields in the data tag may be designated as user-defined.

Time-Sharing of Tag Fields: Alternatively, information may time-share. For example, the air traffic control decision support tool, the Passive Final Approach Spacing Tool (P-FAST), has the runway assignment and arrival sequence number time-share a field in the aircraft data block.

Context-Sensitive Data Tags: Another approach to decluttering the data tags is to use context specific tags or fields in the data tag. An aircraft's data tag would only be displayed if the relationship represented a specified level of interaction with ownship. This would not necessarily mean that the interaction was potentially threatening, though the information displayed would be dependent on the nature of the interaction.

Context-sensitive data tags would provide a mechanism for coding relative altitude: show the data tag with the altitude and climb/descent arrow only if the nearby aircraft is below ownship and climbing or above ownship and descending. Once it is above ownship and continuing to climb, the relative altitude information is not relevant. The following is an example of how a context-sensitive data tag would behave in the en route environment. In this scenario the intruder aircraft is changing altitudes from a level below ownship to a level above ownship. The color designation is: white = ownship; green = aircraft below ownship; white = aircraft at same altitude as ownship; blue = aircraft above ownship. In Figure 6-20[a], ownship maintains Flight Level (FL 270) while intruder maintains FL 250, no data tag information is necessary. Figure 6-20[b] indicates that the intruder has started to climb to FL 290. Since this maneuver will cross the ownship's flight level, the data tag automatically appears displaying information relevant to the situation (i.e., altitude and altitude change information). Figure 6-20[c] shows that the intruder has reached the same flight level as ownship. Altitude information is updated and remains visible. Finally, in Figure 6-20[d], the intruder has reached FL 280 and is still climbing. Altitude information is no longer relevant to the situation and no longer displayed. However, if the intruder were to descend, altitude information would immediately reappear with a downward pointing arrow. It is also advisable to make the complete data tag easily accessible, which could be displayed by simply depressing a function key.



(a) (b) (c) (d)

Figure 6-20. Context-Sensitive Data Tag

In another scenario, the ownship may be requested to self-separate for an in-trail terminal approach. In this case, tag information such as airspeed and type of aircraft would display automatically next to the lead aircraft icon. The obvious advantage to a context-sensitive approach is that visual clutter is considerably reduced. But also, the appearance of a data tag provides the pilot with a visual alert of a potential traffic problem and a clear indication of the nature of that problem.

Another potential context sensitive behavior of the data tag may be to disambiguate similar-appearing tags as shown in Figure 6-21. This can be particularly important in the terminal environment of a hub-and-spoke airport, where most of the aircraft in the airspace have the same company call sign. When a pilot is asked to identify and follow another aircraft into the arrival stream, the potential consequences of selecting the wrong aircraft to follow can be severe. To guard against this possibility, the system might identify flights with similar appearing call signs (such as NWA101 and NWA110) and highlight the distinctive parts of the tag to draw pilot attention to the fact that there's a similar call sign on the display and that special attention is required to ensure that the correct aircraft is selected.

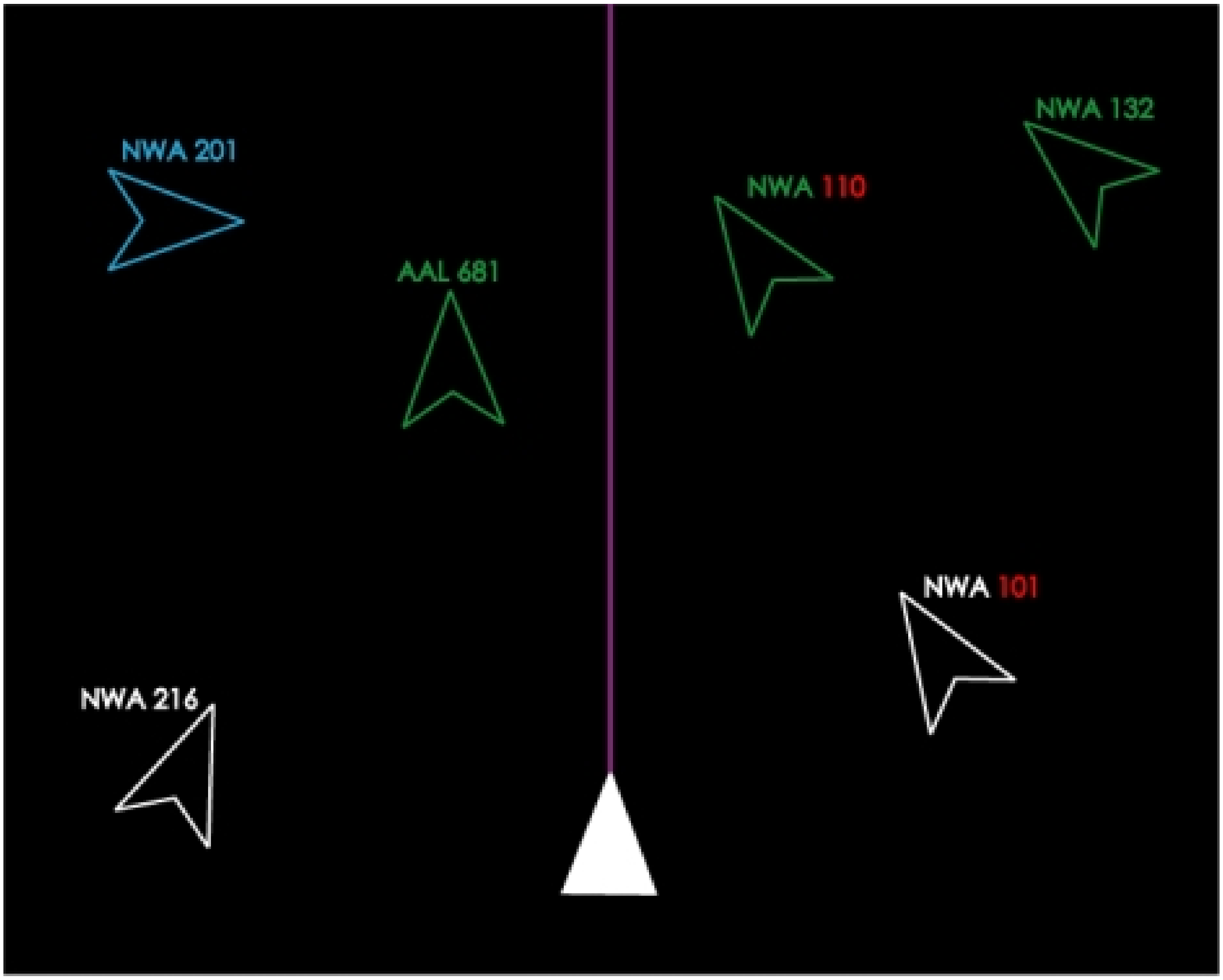


Figure 6-21. Disambiguated Similar-Appearing Data Tags

6.3.10 Data Block Selection

To minimize display clutter, pilots may not want to continuously display the complete data block for each traffic aircraft. Therefore, a method must be developed so that pilots may select to view the complete data block for selected single or multiple traffic aircraft.

Recommended Data Block Selection Method – The best method for selecting a specific traffic aircraft, and the appropriate method to select desired items, *are issues that require further research.*

6.3.11 Future Position

In addition to the current aircraft position, information regarding the predicted future position of the aircraft should be displayed. See Section 7.1, Self-Separation Assurance/Trajectories, for more detailed information.

- State: A predictor extrapolated from current state data becomes invalid the moment the aircraft deviates from its current heading or altitude. Because state information does not provide information as to when the pilot plans to maneuver, a state-based predictor is likely to become invalid within a relatively short period of time (generally within five minutes).
- Intent: Intent data, based on the current FMS flight plan, will take into account trajectory changes as long as the aircraft is following the FMS flight plan. Future position based on intent data is likely to provide long-term, more reliable information as to the pilot's intended path. Results of studies indicate that pilots overwhelmingly prefer long term intent data (FMS flight plan and vertical change point information) to short-term intent (e.g., heading change) or current state vector data (Cashion & Lozito, 1999).

However, it should be noted that long term intent data will be subject to several sources of uncertainty. For one, wind uncertainties prevent precise prediction of future trajectories. Various types of error, including data entry error, mode selection error, communication errors, and so forth are another. Riley (1996) documented a large number of scenarios and situations where intent data can be incorrect and misleading due to errors, loss of coordination between humans and automation, and several other factors.

Recommended Future Position Information – Intent data, in general, provide a more accurate representation of actual future aircraft position than state data. However, intent data are still subject to uncertainty, which should be reflected in the indication of future position. *The exact method by which this uncertainty should be indicated is still an area of research*.

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7. EN ROUTE FREE MANEUVERING

For DAG to be a feasible concept, pilots must be able to maintain separation from traffic aircraft in the environment. This section discusses self-separation, and conflict management methodologies to assure that separation is maintained. The information requirements for en route free maneuvering tasks are derived from CE 5. These requirements are listed in Table 2 (see Appendix). An example of some of these features is shown in Figure 7-3 at the end of this section.

7.1 SELF-SEPARATION ASSURANCE

To maintain appropriate separation from traffic aircraft, a pilot must be aware of where the traffic aircraft are located currently, and where they will be located in the future. *State* information (see also Section 6.2.12, Future Position) is an extrapolation of the current position and speed. State data assume that the aircraft will maintain the current heading and speed and draws a straight line path from the current position out to the estimated future position at whatever distance (time) is designated. Because it is unrealistic to assume that an aircraft will maintain the same parameters (due to winds, turbulence, weather, planned or unplanned trajectory changes) for an extended period of time, state data generally becomes invalid quickly – after approximately five minutes. One implementation of *intent* information uses FMS data to plot the aircraft's flight plan. The FMS waypoints and arrival times are known. Because intent data are based on an actual plan, it is valid for the duration of the flight, unless the pilot re-plans or deviates, or at any time when the pilot doesn't fly in an FMS mode. An alternative implementation of intent information is the Mode Control Panel (MCP) settings. A more reliable implementation would incorporate the flight plan, the MCP settings, and the mode, and broadcast the future trajectory based on the flight path targets (FMS or MCP) that the aircraft was actually flying to based on its current flight control mode.

However, it is important to recognize the essential unreliability of even this level of intent data. One scenario in which it would be misleading has to do with the fact that there are multiple types of actors (human and automation) and multiple communication channels. During adverse weather events, it is possible that pilots and controllers may coordinate over voice radio channels while the automated route planning and conflict detection systems are communicating over digital data channels. If the pilots and controllers develop a coordination plan that involves future transitions from FMS modes to heading and altitude change modes, but these data are unavailable to the automated systems, the automation will continue to broadcast misleading intent data based on flight plan contents and current modes.

It is also important to recognize that in a human centered automation philosophy (Billings, 1992), the pilot should be allowed the discretion to use or not use automation as the situation warrants. An open question, then, is how aircraft intent data can be determined when the pilot is flying the aircraft under manual control. If automatic control is required for operation in certain airspace types due to the need for intent data, this may have implications for safety, skills retention, and pilot authority.

7.1.1 Ownship Trajectories

Ownship State-Projection Trajectory: This trajectory is based on ownship's current position, speed, heading, and altitude. The estimated future position is a straight line extrapolated from these data. Because the future position is based solely on the current position, state trajectories become invalid after approximately five minutes.

Ownship Intent Trajectories: Intent trajectories start with the same information as the state trajectories: current position, speed, heading, and altitude. However, in an aircraft environment where the ability to broadcast FMS flight plan data is available, intent trajectories show the actual flight plan of an aircraft as long as the aircraft is operated in FMS modes. An intent trajectory should show the planned route, indicating any trajectory change points (TCPs). Uncertainty of the intent data should also be indicated.

Ownship Trajectory Color: Solid magenta line (MD-11)

Recommended Method for Displaying Ownship's Trajectory – Conventional symbology uses a solid magenta line to display ownship's trajectory. Intent information is the preferred source of trajectory data. Uncertainty of the intent data should also be indicated.

7.1.2 Traffic Aircraft Trajectories

Traffic Aircraft State-Projection Trajectory: Traffic aircraft state trajectories are calculated the same way as ownship state trajectories are calculated.

Estimated Intent: The broadcast flight plan, consisting of traffic position, speed, heading, altitude, extent of turn (through next two TCPs).

Traffic Aircraft Intent Trajectory: Traffic aircraft intent trajectories are based on the FMS filed flight plan. It should indicate any TCPs along the planned route. Flight level should also be indicated, so that pilots may anticipate the point where the aircraft will level off.

Traffic Aircraft Trajectory Color: For either state or intent trajectories, traffic aircraft trajectories should be distinguishable from ownship's trajectory. If traffic aircraft are color coded to indicate altitude relative to ownship (see Section 6.2.5, Traffic Aircraft Color), trajectories could be shown in the same color as the traffic aircraft. However, issues arise if the flight level of the traffic aircraft changes – to be consistent with altitude color coding, the trajectories should change color, thereby causing visual clutter.

Recommended Method for Displaying Traffic Trajectories – Intent information is the preferred source of trajectory data. A method should be provided to allow the flight crew to easily display and hide traffic trajectories. *The most appropriate method for presenting changes in trajectory altitude must still be researched.*

7.2 AIRBORNE CONFLICT MANAGEMENT (ACM)

The ACM concept is described in RTCA/DO-263, *Application of Airborne Conflict Management: Detection, Prevention, & Resolution.* The three functions, conflict detection (CD), conflict prevention (CP), and conflict resolution (CR), are built around two zones that encase any particular aircraft and move with it. *Note: The concept of the Protected Airspace Zone (PAZ), as used in RTCA/DO-263, has been refined by defining two new terms, Assured Normal Separation Distance and Conflict Detection Zone (RTCA SC186 Airborne Conflict Management Application Description, February*, 2002).

These zones are defined by a number of parameters. Some of these parameters, such as position uncertainty, are dynamically calculated; others such as Assured Collision Avoidance Distance (ACAD) and Assured Normal Separation Distance (ANSD) are fixed.

The navigation and surveillance uncertainties are among the factors that determine the zone sizes. The absolute position uncertainty is often larger than the relative position uncertainty. The vertical separation minima are an example where the more accurate relative altitude is used to reduce separation minima compared to horizontal separation where multiple radars cause relatively large separation minima. The fact that Differential GPS (DGPS) provides increased absolute navigational accuracy is an illustration of the power of the relative navigation phenomenon. Therefore using the relative uncertainties instead of absolute uncertainties reduces the required separation minima. This effect plays a role in determining both the horizontal and vertical dimensions of the zones used for airborne separation assurance.

ACAD is used in collision avoidance and is the minimum assured vertical or horizontal distance allowed between aircraft geometric centers. If these distances are simultaneously violated, a collision or dangerously close spacing will occur. These distances are fixed numbers calculated by risk modeling and initially will be based on ACAS (the European acronym for TCAS) separation distances.

Correspondingly, the ANSD is used in conflict avoidance and is the normal minimum assured vertical or horizontal distance allowed between aircraft geometric centers (formerly termed the loss of separation (LOS) or protected zone).

The Collision Avoidance Zone (CAZ) is the system-measured area that is sized just large enough that the actual distance between aircraft is not reduced below the ACAD. The CAZ is defined by the sum of ACAD and position uncertainties to provide an airspace and legal buffer for the pilots' situational awareness. The CAZ is used to provide collision avoidance in the case of pilot or system failure in maintaining normal separation.

The Conflict Detection Zone (CDZ) is defined by the sum of ANSD, position uncertainties, and trajectory uncertainties. The system is designed to maintain this separation (as measured by the system) between aircraft in a pair. Avoiding CDZ penetration will ensure that legal separation is maintained. For cases where no legal separation standard exists (such as a GA VFR traffic pattern), CDZ alerts will protect either a fixed or a pilot-selectable ANSD. Initially the pilot or system will change the ANSD for different phases of flight, or varying operating environments.

Trajectory uncertainty is a measure of predictability of the future trajectory of each aircraft. Currently the vertical separation is small, in part, due to the predictability of staying at an assigned altitude. If trajectory predictability can be improved in the horizontal dimension, then the separation could be reduced appropriately. For example, an aircraft broadcasting its trajectory intent would have a much smaller trajectory uncertainty than an aircraft not broadcasting its trajectory intent.

It is expected that ATC separation standards will be reduced as ground systems are updated to take advantage of the increased accuracy of ADS-B, thus allowing more accurate determination of traffic position by controllers. The CDZ and ANSD should decrease and/or change shape accordingly and may not be cylindrical. Conflict pairings between well-equipped aircraft (e.g. better accuracy, availability, integrity, and continuity) may use smaller separation than pairings between aircraft with less capable systems. As such, CDZ dimensions will become a function of equipage.

Initially the ANSD will be set to a value that corresponds to current separation standards. The system would add any position and surveillance uncertainty to compute the CDZ. If the system were used for a separation task (not with separation responsibility), this will ensure that the ACM system guides the aircraft to a distance that is compatible with a ground radar based system. If the system is only used for backing up the controller, then the ANSD could be set to a distance less than separation standard to reduce nuisance alarms.

When the controller has the same surveillance source as the ACM system, then both the ground and ACM (ANSD) systems could use fixed distance(s) less than the current standards. Both the controller and pilot would know that the ACM system was adding a variable surveillance component to the distance it was avoiding other traffic.

The same would also be true of any other dynamically measured component that could make up part of separation. Some of these components could be encounter geometry, aircraft equipage, the certainty of aircraft intent, etc. A safety analysis would have to show that a separation standard with these variable distances is acceptable. This safety analysis would also have to determine if variable separation standards are acceptable to the controller and pilot. Again the ground system must have the same information as the ACM system to insure compatibility.

CP and CR are built around two zones that encase any particular aircraft and move with it. These zones are defined by a number of parameters. Some of these parameters, such as position uncertainty, are dynamically calculated; others such as ACAD and ANSD are fixed. Figure 7-1 summarizes starting points for research and implementation.

	GA Traffic Pattern	Terminal Area	High Altitude Enroute
CDZ Horizontal Size	750 feet. Default may be changed by pilot	3 NM	5 NM
CDZ Vertical Size	+/-200 feet. Default may be changed by pilot	+/-500 feet	+/-600 feet
Low Level (LL) Alerting Parameters	>15 sec*	>90 sec	>120 sec
CDZ Alerting Parameters	15 sec*	90 sec	120 sec
CAZ Horizontal Size	200 feet	1000 feet	2500 feet
CAZ Vertical Size	+/-200 feet	+/-200 feet	+/-300 feet
CAZ Alerting Parameters	15 sec*	45 sec	45 sec
CDZ Alerting Method	Caution	Caution	Caution
CAZ Alerting Method	Warning	Warning	Warning
Required Terminology	No Change	No change	No change

Figure 7-1. Airborne ACM Initial Parameter Estimates

- Alerting times are partially based on the following (derived from RTCA/DO-263):
  - Pilot response times to CDZ alerts shall be consistent with the requirement to achieve the necessary lateral and/or vertical separation.
  - Pilot response times to CAZ alerts shall be consistent with the requirement to avoid a midair collision.
- Alert times are defined as the time the pilot must be alerted to prevent an actual penetration of the corresponding zone. They are based on a number of factors which include:
  - Crewmember recognition of the situation
  - Decision on a strategy to resolve the conflict
  - Coordination of any desired action with ATC (if required)
  - Input of the desired control changes
  - Change in aircraft state vector that avoids the penetration.

7.2.1 Conflict Detection

Several methods have been implemented to indicate a potential conflict. It is important that when a traffic advisory is issued, the pilot understands exactly what the advisory implies. Pilots need to know the urgency of the situation. They should be able to easily identify which aircraft is causing the alert and be able to prioritize the detected conflicts as a function of their time horizon (van Gent, et al., 2000). Finally, pilots would prefer an indication of where the potential conflict is predicted to occur. The incorporation of the ANSD, CDZ and CAZ explicitly includes position uncertainties to provide an airspace buffer and legal buffer for the pilots situational awareness. Additional awareness and safety buffers are provided by the alerting parameters (i.e., times) for the LL, CDZ, and CAZ.

The conflict probe look-ahead range should prevent missed alerts while minimizing false alarms. The probes should avert a worst-case scenario in which the resolution of a false alarm leads to a missed alert (Couluris, 2000). The probe should also consider trajectory uncertainty and calculate potential conflicts based on position uncertainty.

Conflict Alerting: The severity of the advisory should be obvious, as well as the amount of time the pilot has to make corrections. For example, the advisory should distinguish between possible loss of separation (LOS) and a possible collision. Both visual and aural alerts should be implemented. Currently, ATC separation standards are usually distance-based. These current standards were not explicitly derived from a system level analysis. Instead, they have historically evolved from experience, based on the limited accuracy of the ground systems and the controller's ability to discern traffic position. Some procedural separation standards are time-based. Future separation standards, based on more accurate and timely position and intent information, may be significantly reduced. ACM procedures are designed to facilitate translation of these capabilities into reduced separations. In the operational concept (RTCA SC186 Airborne Conflict Management) volumes of airspace are defined corresponding to the phase of flight, level of threat and legal separation standards.

Visual Alerting: For any conflict alerting system, the coding used to indicate the severity of the conflict should provide an indication of the amount of time available to remedy the situation – different methods of coding should have explicit rules attached to them. If color coding is used, it should reflect color coding convention (green, amber, red), where different levels of alert may represent the amount of time to the predicted conflict (e.g., amber alerts indicate x minutes until predicted CDZ penetration). General information regarding visual alerts may be found in *Flight Deck Alerting System (FAS)* (SAE ARP4102/4, 1999). Several methods of visual alerting may be used to attract the pilot's attention in critical situations and draw attention to primary information. These methods include:

- Highlighting: To reduce the emphasis on color coding, text or symbology may be highlighted by brightening the characters or increasing their intensity. *Highlighting* is achieved by increasing line thickness of a symbol. *Intensity coding* is achieved by using increasing 'color' intensity while line thickness is held constant. In both intensity coding and highlighting, a single color or hue is used. Examples of both highlighting and intensity coding are shown in Section 6.2.1, Waypoint.
- Flashing and Blinking: For critical information that requires immediate attention, such as indicating an impending conflict, symbols may flash. Although a flashing symbol is effective at getting attention, it may also be irritating or difficult to read. The recommended flash rate is 0.1 to 5 Hz, with 2 to 3 Hz preferred (Doc 9758-AN/966, 2000). No more than two levels of blinking should be used – the users may have difficulty distinguishing between levels. Because these methods may make text difficult to read, do not use flashing or blinking for critical text or numbers, or items that need to be read quickly. The pilot should be able to turn off blinking or flashing. Use these methods sparingly, as they become distracting. These methods may be less effective on a display where text and symbols are constantly moving, and are not recommended for use on a CSD.
- Increased Font or Character Size: Increasing the size of the text or symbol is effective in indicating what information requires attention. Because this is a relatively subtle method of coding, it may be more effective on a relatively clean display (e.g., emphasizing one item in a group, such as highlighting a specific aircraft ID out of a list of aircraft IDs) rather than on a cluttered display.

Recommended Visual Alerting Methods – Visual alerts should provide effective means of 1) alerting the flight crew to conditions requiring attention and 2) be unique enough to provide feedback as to the type of action required by the crew. Flashing and blinking are NOT recommended methods of visual alerting for the CSD. *The exact nature of visual alerting appropriate for DAG is a topic requiring further research.*

Aural Alerts: Aural alerts provide a redundant source of information to alert the pilot to information provided on the displays. When paired with visual cues, they allow the pilot to devote less time to instrument scanning and focus on other relevant tasks (Wiener & Nagel, 1988). Aural alerts may consist of dedicated tones or voice alerts. TCAS implements voice alerts whenever a traffic advisory or resolution advisory is issued. These voice alerts are typically two or three word phrases that either provide information (e.g., "Traffic, Traffic") or explicit instructions ("Adjust Vertical Speed, Adjust") (FAA, 2000a). Detailed information on the implementation of aural alerts may be found in *Human Interface Criteria for Cockpit Display of Traffic Information Technology (*SAE ARP5365, draft 2000), and *Flight Deck Alerting System (FAS)* (SAE ARP4102/4, 1999).

Recommended Aural Alerting Methods – Voice messages should be preceded by an appropriate warning/caution tone. Aural and voice alerts should follow recommendations outlined in *Human Interface Criteria for Cockpit Display of Traffic Information Technology (*ARP 5365), and *Flight Deck Alerting System (FAS)* (SAE ARP4102/4, 1999). Although these documents provide general guidance on voice messages, *the exact wording of DAG concept-specific voice messages requires further research.*

Intruder Aircraft Indication: One method of indicating which traffic aircraft is causing the alert is to change the way the symbol for that aircraft is depicted on the display. Several of these methods have been implemented:

- Highlight the aircraft symbol (make the symbol brighter)
- Fill in the symbol if it was previously unfilled (NASA Langley AUTRII)
- Change the color of the intruder to match the alert color (NASA Langley AUTRII, NLR)
- Changed to a completely different symbol (TCAS II)
- Box the intruder's data block (NLR).

If more than one conflict occurs simultaneously, all aircraft which are in conflict with ownership should be indicated. A method should be provided to indicate the priority (e.g., time to conflict) of the conflicts so that the flight crew knows which to resolve first (van Gent, et al., 2000).

Recommended Intruder Indication – The method used to indicate which aircraft is causing an alert must be considered in conjunction with the alerting scheme and the color/symbology selected for normal traffic aircraft operations. If the CSD is to be integrated with existing TCAS capability, TCAS symbology must also be considered. *The exact nature of indicating which traffic aircraft is the intruder is a topic of research.*

Conflict Location: Research indicates that the information required by pilots to detect conflicts includes aircraft speed, track, speed change, and turn rate (van Gent, et al., 2000). Several methods may be employed to indicate to pilots where potential conflicts exist.

- <u>No-Go Zones:</u> Because time will be critical during any potential conflict situation, pilots need to easily identify conflict areas without calculation, estimation, or conjecture. Therefore, the necessary parameters (speed, track, speed change, and turn rate) could be combined into an integrated display of a 'no-go' area (van Gent, et al., 2000). One method that has been tested uses no-go bands on the heading, speed and vertical speed indicators to indicate the headings and speeds to avoid so that a conflict may be prevented within a certain period of time (Hoekstra, et al., 2000). Hoekstra, et al. (2000) describe a system (Predictive Airborne Separation Assurance System (PASAS)) in which amber and red bands are depicted on the PFD and ND to alert pilots to headings and speeds *not* to follow. The genesis of this concept was the realization that pilots need to avoid maneuvers that will result in a conflict within a certain amount of time. To avoid these potential conflicts, pilots simply need to know the actions that will result in a conflict (Hoekstra, et al., 2000). The bands provide unambiguous indication of maneuvers to avoid without requiring the pilots to make computations or estimations. Amber bands use a look-ahead time of 5 minutes and 20 seconds; red bands use a look-ahead time of 3 minutes (Hoekstra, et al., 2000).
- <u>Circle Around Conflict Area:</u> Absolute position of the conflict may be indicated by a circle around the conflict area (Hoekstra, et al., 2000), as shown in Figure 7-2. The size of the circle may correspond to the protected zone of the aircraft. Protected zones may also be indicated for both ownship and traffic aircraft. If pilots know where the protected zones are, they can focus on keeping the zones from intersecting.

Recommended Conflict Indications – Pilots require several pieces of information in the event of a detected conflict. They need to know *where* the conflict is likely to occur, if any *uncertainty* is associated with the conflict (e.g., location or likelihood of occurrence), which *aircraft (intruder)* is causing the conflict, the best *action* to take (or, the action *not* to take), and the amount of *time* they have to resolve the conflict. Since time will be limited, it is important to provide information that can be easily translated into an action. Conflict prevention bands, such as those implemented with PASAS, have shown some promise. They provide information on criticality/time to conflict (color coding) and indication of what actions the pilot should take. However, *the exact method that is appropriate for indicating conflicts is still a topic of research.*

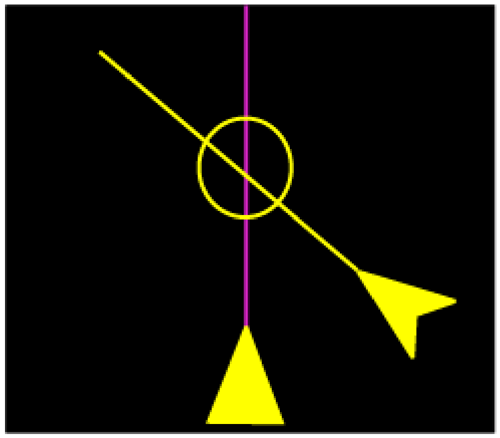


Figure 7-2. Conflict Location

7.2.2 Conflict Resolution

Several pieces of information are required by pilots before they initiate a change to the flight plan. Pilots may have several options in how to resolve any given conflict. These options include changes in heading, speed, altitude, or vertical speed.

In general, heading changes are easier to assess on a 2D display than on a 3D display (van Gent, et al., 2000). Vertical (i.e. altitude) changes are easier to assess on a 3D display than on a 2D display (van Gent, et al., 2000). However, it has been documented that vertical resolutions are the most time and cost efficient (Hoekstra et al., 2000). Considering the number of options pilots have in selecting a conflict resolution, and given a limited amount of time, some of this information can be integrated and extrapolated to give pilots a preview of the results of a certain action. Or, information may simply be presented in a go-here or no-go fashion, similar to the PASAS bands.

TCAS implements resolution advisories via vertical speed or pitch angle changes (FAA, 2000a). Resolution advisories are required to be displayed twice – once in the primary field of view of both pilots. TCAS presents several sources of information for resolution advisories:

- Instantaneous vertical speed indicator (IVSI): red and green LEDs or arcs around the perimeter of the display indicating the appropriate vertical rates to avoid (red) or achieve (green).
- Vertical speed tape that is part of the PFD: red and green indications implemented as in IVSI
- Pitch cues displayed on the PFD.

NASA ARC has implemented the Advanced Route Assessment Tool (ARAT) (Mafera, Helbing, & Duley, in press) to allow pilots to change trajectories. When activated by the flight crew, the ARAT displays an alternate flight path that is, initially, identical to the ownship's active flight plan. The alternate flight path (presented as a solid gray line) will overlap, but not obscure, the active flight plan. In order to make horizontal changes to the flight path, the flight crew must manipulate the waypoints on the alternate flight plan by moving or deleting existing waypoints and/or inserting new waypoints. The ARAT immediately redraws the alternate flight path by connecting the change to the existing waypoints each time a change is made. The underlying, active flight plan becomes visible at this point. Similarly, altitude changes can be constructed by modifying the alternate flight path. Altitude changes are accomplished by adding, moving, adjusting the magnitude of, and/or deleting vertical trajectory changes. Although the process involved in constructing vertical trajectory changes is slightly different than for horizontal changes, the result is a three-dimensional flight path. As the pilot manipulates the waypoints, the ARAT system indicates whether the conflict is resolved or not, and whether any new conflicts are created by the new flight plan. This method allows pilots the flexibility to change a flight plan, point by point, to achieve the desired route and receive instantaneous feedback on the changes.

Researchers at NASA LaRC have implemented the Autonomous Operations Planner (AOP) to assist pilots with conflict resolution. This tool assesses current ownship position and any weather, SUA or traffic conflicts that may occur between ownship's current position and the next TCP. The AOP continuously updates a best resolution to ensure that ownship will avoid all conflicts between the current position and the next TCP while still meeting its RTA. Although the AOP is constantly revising its best resolution, the resolution displayed on the FMS is static. Because the tool is continuously recalculating a single best resolution based on ownship and traffic position changes, the displayed resolution is only 'best' for a short period of time. In the current implementation of AOP, a pilot who hesitates in accepting or rejecting the suggested resolution may be surprised when, upon accepting the resolution on the display, a different resolution is implemented. The current AOP implementation offers the pilot a new FMS page that can be used to "Accept" or "Reject" the instantaneously best solution. Currently, the "Accept" button indicates that the pilot accepts the displayed resolution and this resolution is programmed into the FMS. The "Reject" button cancels out the resolution displayed on the FMS, but allows the AOP to continue calculating conflict free resolutions. If the pilot does not take any action such as changing heading, altitude or vertical speed, then a new best solution is presented on the FMS. Modifications are currently underway to change the "Reject" button to "Update", thereby providing the pilot with a preview of the latest recommended resolution before making the decision to accept it.

Recommended Conflict Resolution – Automation that provides a single best resolution to the pilots may result in faster, more efficient resolutions than those manually developed by pilots. However, *whether automated resolutions are preferred to or more efficient than manual resolutions is still a topic of research*. If an automated resolution is provided, pilots should have the option to reject this resolution or modify the route with a tool similar to ARAT. If a pilot initiates a manual resolution or revises the automated plan, the pilot should have the capability to preview the plan. The CR system should prevent a pilot from executing a resolution that is outside of the aircraft's handling capabilities, or one that would initiate a conflict in the short term. The conflict resolution algorithm should consider position uncertainty in making its calculations. *The exact method with which resolutions should be implemented is a topic of research*.

Figure 7-3. Example of Basic CSD with Conflict Prevention Features

8. EN ROUTE TRAJECTORY NEGOTIATION

8.1 SHARED SITUATIONAL AWARENESS AMONG STAKEHOLDERS

Because of the emphasis of DAG-TM on the redefinition of user roles and responsibilities to achieve a balance of workload among the users, there will be a greater for close coordination among the users. During trajectory negotiation, it is imperative that current, valid information be shared among the groups. Because these interactions can become quite complex, methods must be developed to facilitate the transfer of information. For example, assuming that FMS flight plans are the determined format of intent information, this information will be broadcast to surrounding traffic when pilots make changes to their flight plans. However, it may be necessary to inform the surrounding flight crew of the updated information in the event that they are creating resolutions to area conflicts, or to provide an indication of the intent to change a flight plan. A number of areas require human factors inputs to ensure the consistency and harmonization of information across stakeholders to facilitate shared SA.

Information Content: Means must be implemented to ensure that all stakeholders receive comparable, if not the same, information. The actual information content should be tailored to meet the requirements of the different stakeholders. A pilot, for example, may require detailed current and forecasted local weather situations to enable him to make tactical decisions, such as whether to fly through an opening in a line of thunderstorms. An ATSP, on the other hand, may need a broader image of the weather situation to allow her to direct groups of aircraft around large weather cells.

Regardless of the level of information required by the different stakeholders, the information should be presented in a way that ensures that the different stakeholders interpret it in the same way. To facilitate common SA, designers should follow some basic guidelines:

- Consistent terminology so that all users understand what is being communicated
- Consistent coding so that levels of weather, for example, all indicate the same severity or impact on flight
- Consistently integrated data so that, for example, intent information does not need to be interpreted based on knowledge of mode logic.

Timeliness of Information: During a simulation at NASA ARC, CE 6 was tested in conjunction with other related concept elements. Both ATSPs and pilots were provided with conflict detection and resolution DSTs. However, the ATSPs had a longer look ahead time than the seven-minute look ahead time provided to pilots (Kopardekar, et al., 2001). Results of the study indicated that both the pilots and controllers seemed comfortable with the procedures related to trajectory negotiation. However, because the ATSPs' conflict detection tool provided a longer look ahead time than that of the pilots, and because ATSPs have more experience in detecting conflicts, the ATSPs tended to detect and resolve conflicts before the pilots were aware of them. As a result, the pilots did not initiate trajectory changes often, and they seemed comfortable letting the controllers set the routes. The ATSPs were *uncomfortable* waiting for the pilots to initiate resolutions, and would initiate the trajectory change process before pilots were aware of a situation. Because there was never any conflict between the ATSP and pilot defined trajectory changes, there was never a need for negotiation per se.

Recommended Information Timing – Results of the simulation indicate that information should be provided to the stakeholders simultaneously, or as close to simultaneously as possible. However, the extent to which differences in information timing among groups can be tolerated is still an open area of research.

8.2 COMMUNICATION

As of spring, 2002, procedures for trajectory negotiation have not been defined. As the concept and procedures are developed, required lines of communication among the different stakeholders will become clear. For now, researchers are assuming some sort of communication between the FD and ATSPs, FD and traffic aircraft. Communication with existing NAS stakeholders, or any additional stakeholders that are established to accommodate DAG-TM, have not been defined.

Flight Deck Procedures: On the FD, the PF and PNF will need to communicate with each other, but this requirement is not a departure from current operations. However, some of the information that the two pilots need to communicate may require a different approach to information sharing. As discussed previously, the use of automation may preclude pilots from being fully aware of what the other pilot is doing. A system of checks and balances must be established to ensure that information was communicated successfully and accurately.

Priority Flight Rules: In a decentralized environment such as Free Flight, where responsibility for maneuver coordination is no longer dependent on ATSPS, some sort of priority flight rules must be established to provide a framework in which free maneuvering aircraft could operate. The primary purpose of these rules is to ensure safe separation of all aircraft at all times (Schild & Kuchar, 2000).

Three different types of information may be used in rule-based maneuver coordination (Schild & Kuchar, 2000):

- Position or state information – priority based on simple coordination rules (e.g., VFR rules) based on absolute or relative position.
- Velocity vector information – to determine priority based on vertical rates of the aircraft. Vertically moving aircraft could be assigned lower priority that aircraft maintaining level cruise.
- Intent information (e.g., emergency status, next waypoint) – priority based on estimation of distance to closes point of approach, where the faster aircraft defers to the slower aircraft.

Generally, such rules should be kept simple. Because responsibility for maneuvering decisions remains with a human, it is critical that the operator understand the principles upon which the rules are based. An extremely complex set of rules may allow for misinterpretation. It also results in diminishing returns: as the rules become more complex, the additional gain becomes smaller. Finally, if the operator cannot understand the basis of a conflict decision, the operator may mistrust the system and be less likely to conform (Schild & Kuchar, 2000).

To avoid mismatches between human decisions and the rule base, Schild and Kuchar (2000) recommend that designers consider the following human factors principles:

- The operator may not be able to observer the same information that the rule structure is using. Or, the operator may have additional information that the rule base does not, such as voice communication from the other pilot indicating the intent to maneuver. In such cases, the operator may disagree with the decision automation.

- Human operator can make complex judgments based on an internal set of rules. However, these internal rules may not follow a rigid structure, which makes it difficult for others to predict the final decision.
- Differences in the number of degrees of freedom of action. The rule base may be limited in the number of resolutions that it may consider. For example, it may be programmed to provide only lateral resolutions. A human operator may consider additional strategies, such as a vertical maneuver. Conversely, an extremely complex resolution provided by the rule base may not be as acceptable to an operator as a simple vector change.

Different research programs have identified specific rules to address scenarios that were developed to meet their specific research goals. In it's operational concept, NLR defines "rules of the air" or Extended (or Electronic) Flight Rules (EFR). NLR's rules were defined to require minimal intervention from ATSPs for all possible traffic encounters within the defined scenarios. The rules were unambiguous so that all parties had a clear understanding of the responsibilities of all aircraft. Details pertaining to NLR's rules may be found at http://www.nlr.nl/public/hosted-sites/freeflight-atm/ops_conc.html.

Eurocontrol's Free-Route Experimental Encounter Resolution (FREER) project defined priority rules based on maneuverability and availability associated to sub-phases of flight. The rules define right-of-way priorities for conflicts between two aircraft in an 8x8 matrix. The project also defined rules for conflicts involving more than two aircraft. Details may be found at http://www.eos.tuwien.ac.at/Oeko/RSchild/Rules/id169.htm.

NASA LaRC applied such rules in strategic (longer than 5 minutes look ahead) conflicts in the AUTRII study (Wing, et al., 2001). These rules were selected to address the specific conflict situations developed for the study and for ease of memory.

Recommendations on Priority Flight Rules – In general, rules should be kept simple to avoid misinterpretation and ensure user trust in the system. Safety is a hard constraint in rule design, and is a disqualifying feature of rules that do not comply. Other factors that should be considered in rule design are flight efficiency and the number of maneuvers necessary to attain safe separation. *Further research is required to determine the exact implementation of priority flight rules in DAG-TM*.

8.3 ROUTE REPLANNING

One area which is a significant departure from current operations is route replanning. On the FD, pilots may need the ability to share trial plans with each other to establish common SA.

The PF and PNF may have the capability to plan a trial route independently of each other. In such cases, a means must be developed to allow the pilots to view the other pilots' trial plan. For example, the PNF may be tasked with creating a trial plan. The PF could simultaneously be creating a trial plan. The PF will want to review the PNF's trial plan before proceeding in the approval process. Although the exact method for this transaction has not been established, several factors should be considered. Before viewing the PNF's trial plan, the PF may already have a current flight plan and his own trial flight plan on the display. Now, the PNF's trial plan will be added to the display. In this case, it is possible that three versions of a flight plan may be visible to the PF. Similarly, pilots may review trial plans from the ATSP or AOC dispatcher. A method must be provided to clearly distinguish the active flight plan from any trial plans that may share display space.

Pilots must always know what 'state' the replanning is in – whether a route is current, planned, accepted, or programmed into FMS. If some of the steps in the replanning process are automated (e.g., the route automatically is entered into the FMS when the pilot accepts it), the pilot must be aware of this process and receive some sort of indication that a change has been implemented.

Finally, another area of research is whether or not pilots need to be alerted to the fact that someone is planning a potential reroute for the aircraft. Is it necessary for the flight crew to know that they are about to receive a proposed route change from the ATSP or dispatcher? If so, how should this information be conveyed?

Recommended Route Replanning Indication – If more than one flight plan is indicated on the pilot's display, a method should be provided to allow the pilot to easily distinguish among the different routes. A clear indication should be given to indicate which is the active flight plan, and which ones are trial plans. Color coding or using dashed rather than solid line may be options. However, *the exact nature of coding is still a topic of research*.

9. SELF-SPACING FOR MERGING AND IN-TRAIL SEPARATION

9.1 EN ROUTE: SELF-SPACING FOR IN-TRAIL SEPARATION

Self-Spacing for In-Trail Separation (Sorensen, 2000) and Station Keeping (Agelii & Olausson, 2001) refer to a method of maneuvering to maintain a fixed spacing interval relative to another aircraft. In turn, each successive aircraft spaces on the preceding aircraft, forming a string of self-spacing aircraft along a route. Spacing may be defined as an assigned time or distance behind a lead aircraft. Regardless, the self-spacing procedure distributes the responsibility for separation between the ATSP and the flight crew.

Self-spacing for in-trail separation, though typically discussed within the scope of terminal operations, potentially could benefit the en route environment. A specific area that could benefit is oceanic navigation. Currently, the longitudinal separation standard is 10 minutes (approximately 76 NM at .8 Mach at FL350), if speed of lead aircraft is the same or greater than the following aircraft. The use of self-spacing technology and procedures could allow for the reduction in the separation standard without compromising safety.

A variety of information requirements are necessary for safely self-spacing within the DAG-TM environment. This section discusses some of the fundamental requirements for in-trail separation, but is by no means exhaustive. In addition, recommendations are provided, when possible, as to how these requirements may be implemented into the FD. Individual examples are provided throughout the text while composite CSD prototypes are found at the end of Section 9 (Figures 9-12 and 9-13).

9.1.1 In-Trail Temporal Spacing

In-trail temporal spacing requires the flight crew to maintain an assigned spacing interval behind a designated lead aircraft. The goal is to maintain or reduce the required spacing between aircraft by allocating greater responsibility to the flight crew. A primary challenge is how to present "visual cues or cues communicating separation" to the flight crew that will support a semi-autonomous spacing procedure (Shelden, 2000). The requirements discussed within this document are those necessary for in-trail temporal spacing with the assumption that the task of selecting a lead aircraft to follow is that of the ATSP.

9.1.1.1 Lead Aircraft – A requirement for in-trail spacing is knowledge of the lead aircraft, its location, and flight path. The type of aircraft may also be needed for determining wake vortex behavior. The lead aircraft state and trajectory information would likely be broadcasted (e.g., ADS-B) but, in the event of an unequipped lead aircraft, an ATSP DST could supply this information.

Recommended Lead Aircraft Indication – The lead aircraft may be represented in both symbolic and alphanumeric form. The lead aircraft symbol should be distinct from other traffic symbols. The alphanumeric display will provide a constant information source in situations when the lead aircraft symbol is not in range on the CSD. As part of the traffic display, the lead may be represented as a solid symbol with outline. Symbol color may indicate altitude relative to ownship. For example, in Figure 9-1, the lead is shown at a lower altitude as ownship, thus a solid green symbol with outline. The Aircraft ID and type information should also be available in the data tag.

Figure 9-1. Lead Aircraft with Spacing Information in Data Tag. Lead Aircraft is Currently Below Ownship's Altitude (Indicated By Green Lead Aircraft Symbol)

9.1.1.2 Spacing Guidance – The graphical representation of the time-based spacing interval should function as a support tool for maintaining the required temporal gap. However, "the presentation of the separation cue and related information is the subject of most disagreement" (Shelden, 2000, p. 7). One convention is to represent the spacing interval as a spatial gap between the lead and ownship symbols. The advantage of this representation is that self-spacing and monitoring airborne traffic becomes an integrated task, supported by a common display.

A second convention is to represent the spacing interval as a relative speed with respect to the lead aircraft. The advantage of this representation is that relative speed changes correspond directly to how a flight crew regulates longitudinal spacing. The flight crew is not forced to make the conversion from a change-in-spacing to a change-in-speed. One study found that pilots using a spatial representation (as described above) "would have preferred a spacing cue that told them what to do (e.g., slow down or speed up) rather than what the spacing error was" (Williams, 1983, p. 9).

Recommended Position Indication – Figure 9-2 shows a spacing box that indicates the desired position of ownship in order to maintain the assigned spacing interval. The ownship aircraft symbol will move in front of or behind the box, depending if the spacing interval becomes less than or greater than the assigned interval. If ownship maintains the proper interval, the ownship symbol will be positioned inside the box. The distance between the lead and spacing box represents the proper spacing distance. The segmented line connecting the two corresponds to the temporal gap. In Figure 9-2, each segment is equal to 30 seconds.

A potential shortcoming for this type of symbology is the misconception that it reflects an aircraft's lateral position relative to the proper spacing assignment. A figure, such as the spacing box, used to provide only longitudinal guidance could be misinterpreted as also indicating lateral performance. It may instill a false sense of proper lateral positioning when actual the aircraft is deviating.

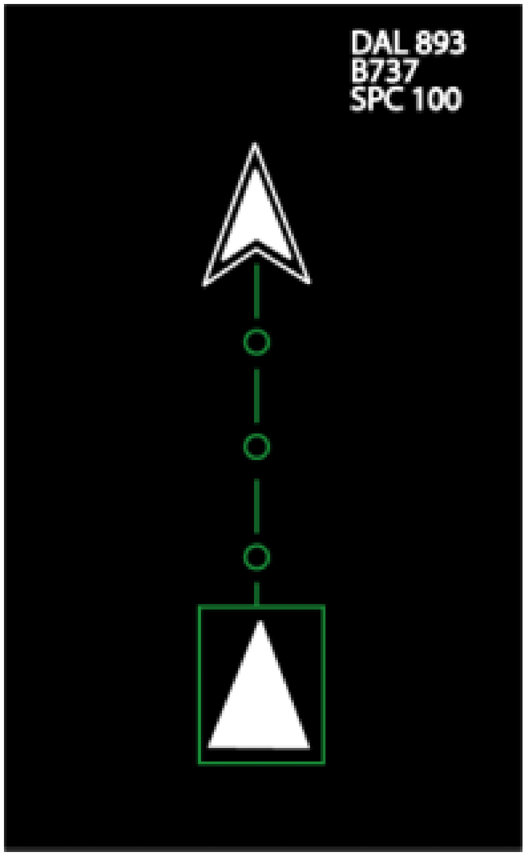


Figure 9-2. Ownship Within the Spacing Box Behind Lead. Lead aircraft is currently at the same altitude as ownship (indicated by white lead aircraft symbol).

Recommended Performance Indication – The range setting may affect the pilots' ability to detect spacing deviations when relying on the spacing box. This inability to detect spacing box deviations is a significant problem since small positioning deviations at a high range setting correspond to large temporal deviations. Spacing box color could be used as a visual cue to indicate whether the assigned spacing is being maintained. While ownship maintains the proper spacing, the spacing box remains green (Figure 9-2). However, if the temporal gap becomes too small (Figure 9-3(a)), the spacing box turns yellow. Similarly, if the gap becomes too big (Figure 9-3(b)), the spacing box turns gray.

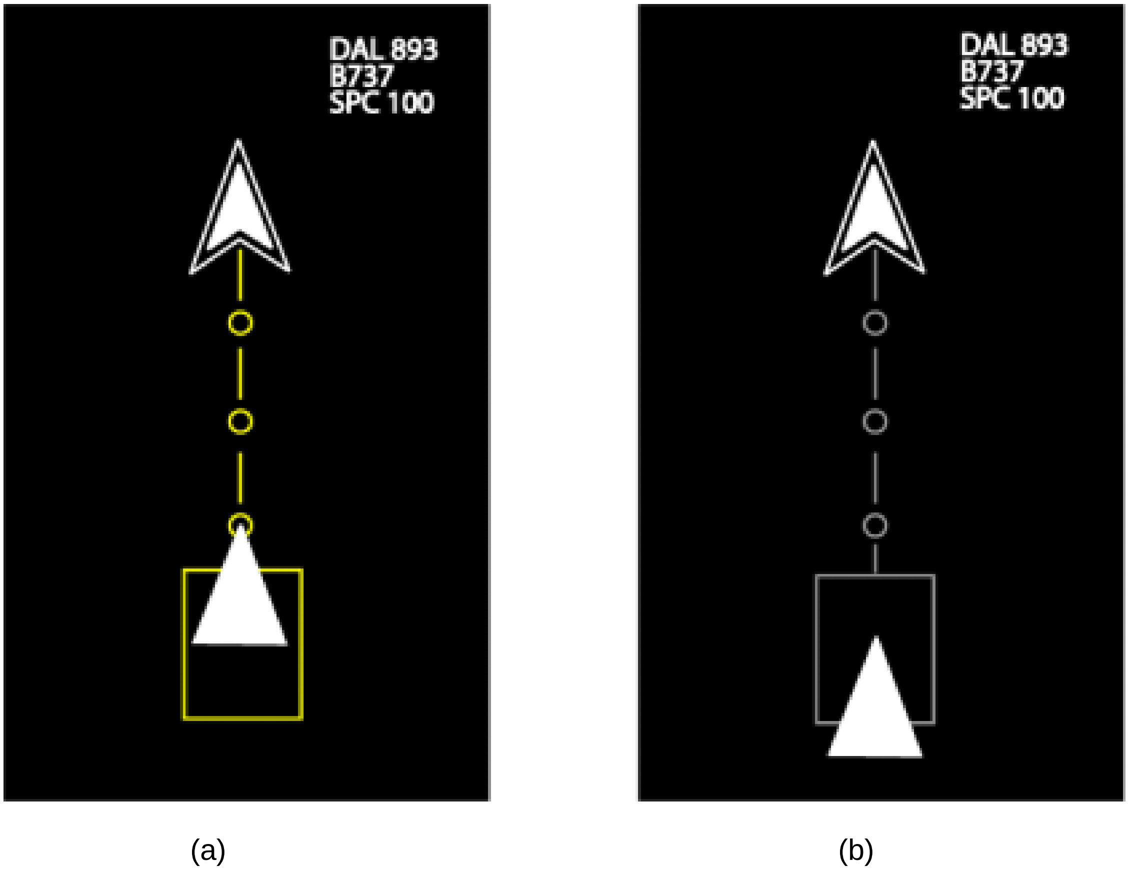
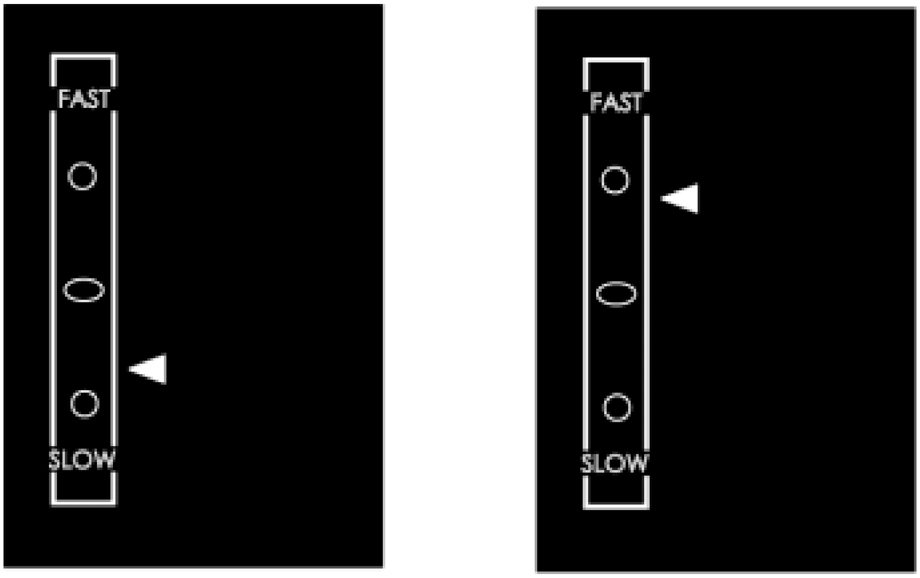


Figure 9-3. Ownship Faster than the Assigned Spacing (a) and Slower (b). Lead aircraft is currently at the same altitude as ownship (indicated by white lead aircraft symbol)

Recommended Relative Speed Indication – A relative speed indicator provides the pilot with relative speed information with respect to obtaining and maintaining the desired spacing interval. A larger than desired spacing interval is indicated by the pointer moving into the “slow” region, signaling that ownship's speed is too slow (Figure 9-4(a)). Likewise, a smaller than desired interval is indicated by the pointer moving into the “fast” region (Figure 9-4(b)). This type of representation is intended to convey relative performance information (i.e., "I'm moving too SLOW" or "I'm moving too FAST") and not to function as a speed command tool (i.e., "Go slower" or "Go faster").



(a) (b)

Figure 9-4. Relative Speed Indicator

9.1.1.3 Ownship Target Speed – Target speed is useful feedback for the pilots when they are trying to maintain the assigned spacing interval. Target speed may be displayed at a fixed location on the display so as to reduce search time, and avoid clutter and legibility problems.

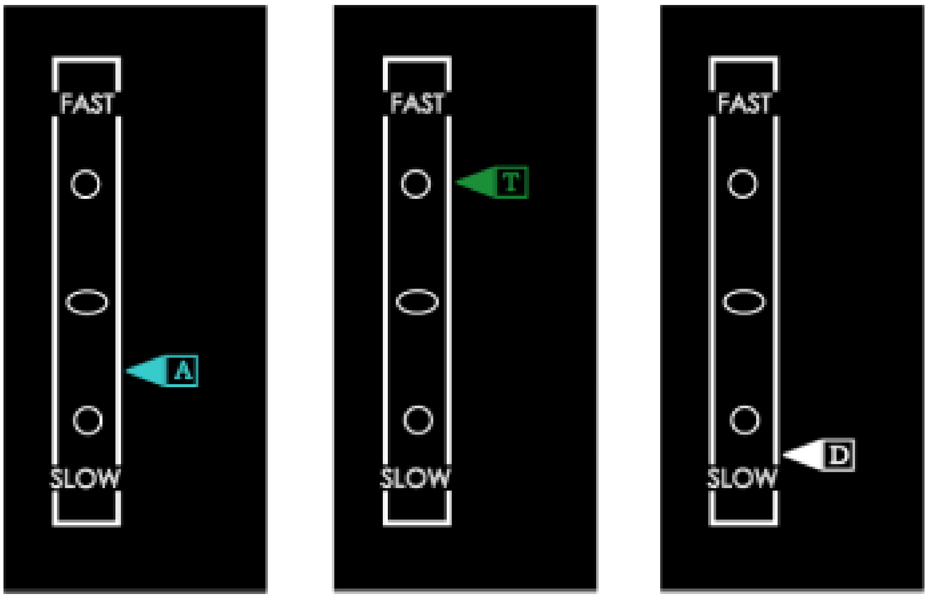
Recommended Method – Ownship target speed should be displayed alphanumerically. If displayed on the CSD, it should appear in a location that will not interfere with traffic display. Also, text color should correspond to other spacing information in order to facilitate perceptually grouping of information.

9.1.1.4 Levels of Engagement – A pilot's ability to interpret the behavior of an aircraft's automation is imperative for safe flight operations. Difficulties arise when the automated plan and the pilot's plan do not correspond (Garland, Wise, & Hopkin, 1999). An example of this occurs when a pilot misinterprets the system's mode status. Sarter and Woods (1995, p. 9) note the "lack of salient feedback on mode status and transitions" as factors contributing to mode confusion.

The CSD should provide obvious and unambiguous cues to which mode, or level of engagement, the self-spacing system is in. This disambiguation is not of trivial concern since there could be a number of levels, some with the capability of transitioning automatically. The following are possible levels for a spacing guidance system:

- *Active* (system is actively engaged and spacing behind a lead),
- *Profile* (system is actively engaged but spacing is not relative to an actual lead),
- *Armed* (spacing parameters are loaded but system is not yet active), and
- *Disengaged* (system was actively engaged but is not now).

Recommended Indication of Level of Engagement – One approach to making explicit the level of engagement is to integrate this information into the tools used for self-spacing. In this way, knowledge of the system's mode is more apparent and does not require a shift of attention to locate the information. Current mode could be indicated by the appearance of the spacing box and relative speed indicator. The example below demonstrates a method of communicating mode information by using redundant coding (e.g., both color and text). Figure 9-5(a) indicates that the self-spacing system is armed by modifying the speed pointer. Similarly, Figure 9-5(b) shows a system that is active with traffic (i.e., spacing to a lead aircraft) and Figure 9-5(c) shows a system that has disengaged.



(a) (b) (c)

Figure 9-5. Examples of Levels of Engagement; Armed (a), Active w/ Traffic (b), and Disengaged (c)

The above example uses the relative speed indicator to communicate the level of engagement, however, this information could be conveyed elsewhere on the CSD. One recommendation is to display self-spacing parameter text (e.g., lead aircraft ID, assigned spacing interval, and target speed) in a color indicative of the current mode.

Auto-Disengagement: It is conceivable that, at some point during the approach, the ownship will not be able to recover from a spacing interval deviation. For example, this could happen if the ownship is forced to maneuver around weather and subsequently increases the interval to the point where recovery is not practical or safe (e.g., increasing ground speed during final approach to close gap). The system must know when it can no longer meet the assigned interval, notify the flight crew of the problem, and terminate the spacing procedure.

9.2 TERMINAL ARRIVAL: SELF-SPACING FOR MERGING AND IN-TRAIL SEPARATION

As part of the DAG-TM CE 11, the flight crew will be required to maintain self-spacing for in-trail separation during arrival. The proposed concept is designed to increase throughput by decreasing the separation between the lead and trailing aircraft. This is accomplished by employing a time-based spacing algorithm that reduces the distance between aircraft as speed is reduced during approach (Williams, 1983). The tasks, or what Sorensen (2000) refers to as "operational modes", identified with respect to the DAG terminal environment are: in-trail temporal spacing (Section 9.1.1); free maneuvering in unstructured arrival corridors (Section 9.2.2); merging onto a common arrival route (Section 9.2.3).

This section discusses some of the unique requirements for self-spacing within the terminal environment. They represent an addition to the requirements discussed in Section 9.1. Information required for standard approach procedures is not discussed unless it poses a unique concern within the self-spacing paradigm.

9.2.1 Initial Arrival into Terminal Area

A time-based spacing interval between ownship and the lead aircraft is assigned by the ATSP upon entering the terminal area. This interval, though not critical for an approach using RTAs, is fundamental to a self-spacing approach. Shelden (2000) asserts that the interval should be presented as an "optimal separation" and not a "required minimum separation." This section discusses information that characterizes the airspace and route geometry of the terminal approach area. Essentially, it will provide the flight crew with a road map of the navigable airspace.

9.2.1.1 Convective Weather – The display of weather in a terminal area environment must take into account a unique set of constraints. Unlike the en route environment, the terminal approach area is a highly restricted volume of airspace. Space in which to maneuver is relatively small when compared with en route airspace. Lateral deviations are constrained by merging streams of arrival traffic as well as large corridors for departure traffic. Vertical deviations are generally not feasible since arrival aircraft follow an approach path that is defined by specific step-downs. To add to these limitations, any decision to deviate around convective weather is highly constrained by time. Furthermore, it is in this airspace that terrain indications are most likely to be needed, adding further complexity to the display.

Recommended Indication of Convective Weather – Considering the relatively high workload associated with a self-spacing task and terminal area maneuvering constraints, severe weather may be best displayed as "no-go " zones (Figure 9-6). In this way, flight crews will not need to assess the severity of the weather and then decide whether to go through it or not. The decision-making process will be reduced to "How do I get around it?" No-go convective weather zones in the terminal area should maintain consistent symbology, such as that used in the en route environment (see Section 6.1.2). However, the appropriate symbology and corresponding level of severity is an issue that requires further research.

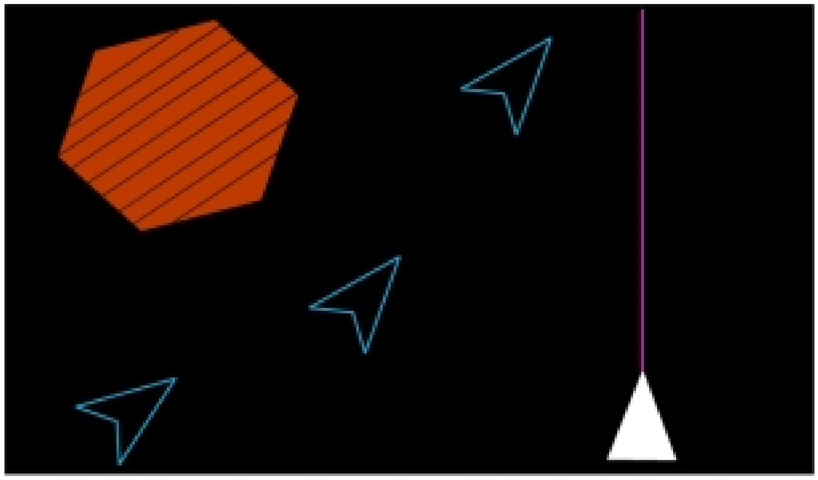


Figure 9-6. Severe Weather "no-go" Area Indicated by Red Polygon

9.2.1.2 Approach Zone Boundary – The approach zone boundary is the border that delineates the arrival corridors from the departure corridors. It may be dynamic in nature, reflecting an airport's runway configuration, traffic flow, departure routes, winds, and weather. Because of airspace dynamics and the opportunity for aircraft to freely maneuver within an arrival corridor, boundary information should be accessible upon TRACON entry, perhaps earlier.

Recommended Indication of Approach Zone Boundary – Arrival zone boundaries could be graphically defined on the CSD. Depiction should follow a standard convention used for restricted areas (e.g., a patterned border, see Section 6.1.1, Special Use Airspace) while remaining discernable from other restricted areas. The area on the departure side of the boundary might be further differentiated by a fill pattern (e.g., a diagonal crosshatch) since this zone represents a highly restricted area. However, it is not clear if the display of approach zone boundaries will introduce excessive clutter, or whether it should be selectable or not. Further research is recommended to determine display format and how soon this information should be made available.

9.2.1.3 Approach Zone Centerline – One benefit to depicting approach zone boundaries is that they create well-defined approach areas or corridors. These corridors, although relatively wide, represent an airport's approach paths. A corridor can be further defined by adding a centerline. There are a couple of advantages to including an approach zone centerline. First, it would provide an approximate linear reference of the center of the corridor. Second, a centerline may represent a default approach route followed by unequipped aircraft (Sorensen, 2000). This indication would provide equipped aircraft with an approximate location and route where unequipped aircraft may be expected.

Recommended Approach Zone Centerline Indication – Centerlines could be graphically depicted (possibly in default mode) in a form/color distinct from the ones used for aircraft flight paths, trajectories, histories, etc. A low contrast, dashed line is one possible representation. Again, further research is needed to determine whether it should be selectable or not to reduce clutter.

9.2.1.4 Merge Points – A merge point is defined as the intersection of two arrival streams. Similar to approach zone boundaries and centerlines, merge point locations are dependent on the dynamics of the airspace. By including centerlines within the approach zone boundaries, these points are graphically denoted by the intersection of the centerlines. However, the display of merge points should not be dependent on the display of approach zone centerlines.

Recommended Merge Point Symbology – Merge points could be distinguished from way-points by including arrival streams in the representation. Graphical display of these points, if not by default, should be easily accomplished and include latitude/longitude information. Figure 9-7 shows a possible representation when approach zone centerlines are not displayed. The merging streams are indicated by the two line segments (at 6 & 8 o'clock) protruding from the waypoint. The third line segment (at 12 o'clock) is the newly merged arrival stream.

Figure 9-7. Merge Point Without the Display of Approach Zone Centerlines

9.2.2 Free Maneuvering in Unstructured Arrival Corridors

The free maneuvering mode as defined by Sorensen (2000) is "the self guidance and separation of each equipped aircraft within unstructured arrival corridors or zones" (p. 10). A properly equipped aircraft will have the authority to tactically maneuver to avoid weather, adjust for approach spacing, and maintain separation. However, along with increased autonomy, the flight crew will be responsible for maintaining separation, staying within the approach zone boundary, and meeting pre-merger RTAs (Section 9.2.3.1). All the information requirements discussed in the previous section (Section 9.2.1) are essential in a free maneuvering mode. This section expounds on additional requirements and its CSD representations.

9.2.2.1 Traffic Intent Information – Within the scope of free maneuvering, the flight crew will have the opportunity to design a flight path during the approach phase. They will also be responsible for maintaining separation from similarly equipped free maneuvering aircraft. This raises the question as to what and how intent information should be communicated to the pilot. Generally, aircraft intent information is described in terms of vertical speed, turn and climb rates, active flight plans, and trajectory change points (TCP). Depicting all this information, either graphically or alphanumerically, is probably not practical within the terminal environment. Barhydt and Hansman

(1999) suggest that the high traffic density and pilot workload associated with terminal area operations may warrant simpler intent information.

Recommended Traffic Intent Symbology – Display of intent information should be selectable in order to avoid excessive clutter. Other relevant information, such as altitude, airspeed, and aircraft type, could be available via an aircraft's data tag. The method used to represent traffic intent information in the terminal area should be consistent with that selected for en route maneuvering. Further research is recommended to determine what and how intent information should be displayed.

9.2.3 Merging onto a Common Arrival Route

It is possible that a number of merges with traffic streams will take place before ownship merges behind the lead aircraft. Though these merges are important steps in the approach, the merge with the lead aircraft will require more precision since this phase could very well represent the closest in-trail spacing during the entire approach scenario. This section describes the information requirements for meeting a pre-merger RTA when the lead aircraft is not in the same arrival stream as ownship.

Once an equipped aircraft crosses into TRACON airspace, it is allocated a position in the arrival stream by assigning it a lead aircraft and a spacing interval. However, the assigned position may not always be directly behind a lead aircraft if the lead and ownship arrive at different feeder fixes at the TRACON boundary. In this scenario an equipped aircraft may be required to self-regulate its approach in order to be properly spaced when the merge occurs. This could be accomplished one of two ways. The flight crew can either maintain spacing by meeting a number of pre-merger RTAs or use a “ghost” lead aircraft to simulate in-trail spacing (Sorensen, 2000). A ghost aircraft symbol would represent the relative position of the lead aircraft if it were in the same arrival stream as ownship. Proper spacing behind it would result in the desired spacing interval once the two aircraft merged. The information requirements and CSD implementation are considered for both pre-merger methods.

9.2.3.1 Lead Aircraft – The lead aircraft state information may aid maintaining the required spacing while merging, and should be available to the flight crew. However, relying solely on the data tag as a source is not practical since the lead aircraft symbol will not always be within the CSD range setting.

Recommended Method – This information could be displayed in a fixed location on the CSD screen along with aircraft ID and type. It should be consistent (e.g., same text color and location) as other spacing information.

9.2.3.2 Pre-merger RTAs – A pre-merger RTA is an assigned location and time that an aircraft is assigned to meet. Section 6.2 describes some of the current display symbology for waypoints and RTAs. RTAs should follow the same convention, however, with the addition of time information.

Recommended Method – Figure 9-8 shows an active RTA with latitude/longitude, flight level, time of arrival, and the current deviation. The “+2 SEC” indicates that ownship is two seconds ahead of its scheduled arrival time. It may not always be necessary to display all the information. Figure 9-9 shows the same RTA with a filtered data tag. Flight level, particularly when ownship is at that same altitude, perhaps should be selectable. The current time deviation may be more informative than the time of arrival since it provides the flight crew with feedback to their performance. However, the pilot still must convert the time deviation value into a speed change before he can modify their arrival time. Therefore, a target speed may be more useful for maintaining an accurate RTA (see next section).

Figure 9-8. RTA with Complete Data Tag

Figure 9-9. RTA with a Filtered Data Tag

9.2.3.3 Time of Merge Behind Lead – The time until ownship merges behind the lead aircraft may be communicated in either absolute or relative terms. Either way, this information provides the pilot with a more complete picture of the approach scenario.

Recommended Indication of Time of Merge – Since it is not apparent which is the more useful format for the merging task, it is recommended that both be displayed in a location consistent with similar text information. However, further research is recommended in determining which format is more supportive.

9.2.3.4 In-Trail Merge Point – The in-trail merge point is the location at which ownship merges behind the lead aircraft. This point is likely to be the beginning of the closest in-trail spacing segment. The point could be located anywhere between the feeder fixes at the TRACON boundary and the FAF, depending on aircraft routes and the configuration of the approach space.

Recommended In-Trail Merge Point Indication – The location of the in-trail merge point could be displayed alphanumerically in the same proximity as other self-spacing parameters (e.g., spacing interval and target speed) since this location may not always be visible on the CSD screen. The distinction between merge point and in-trail merge point symbols should be apparent. In this example green is used to distinguish the in-trail merge point. Figure 9-10 shows an in-trail merge point.

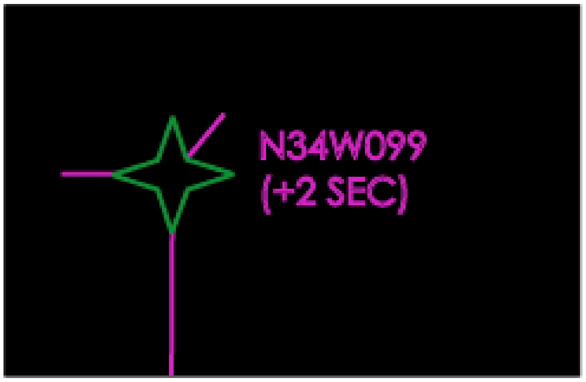
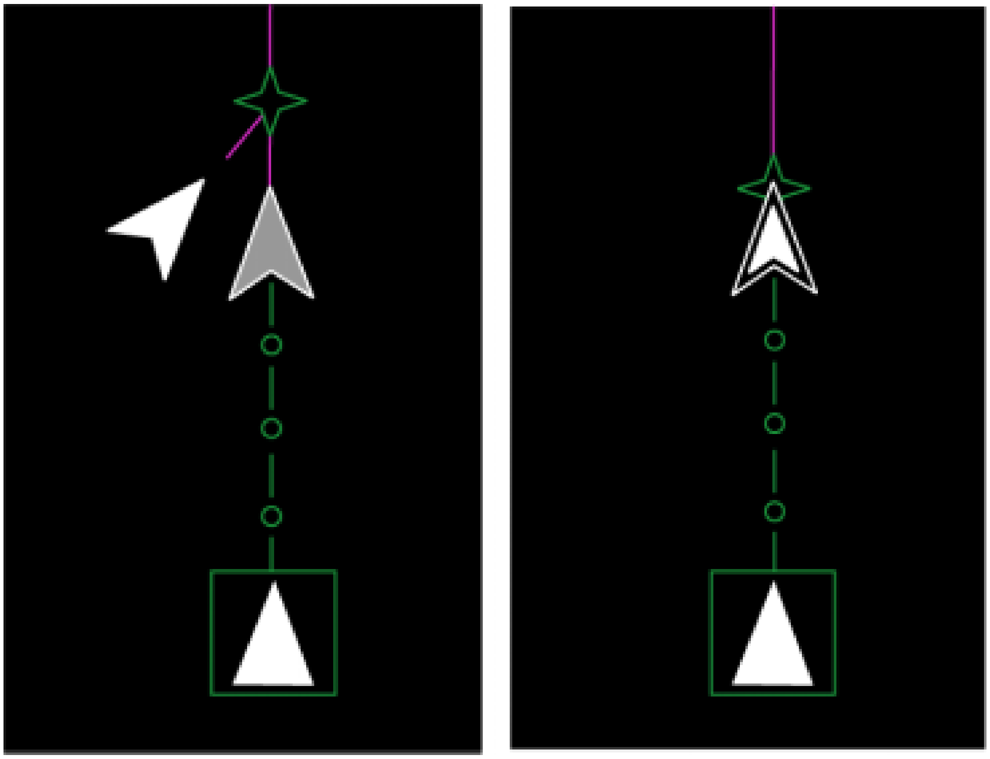


Figure 9-10. In-Trail Merge Point

9.2.3.5 Spacing Guidance – The ghost aircraft symbol would provide support during the merging portion of the approach. As the actual distance between ownship and lead aircraft decreases, the ghost and lead aircraft symbols will both become visible on the CSD (Figure 9-11(a)). Eventually, these two symbols will overlay on the display (Figure 9-11(b)). This superimposing will immediately precede the arrival of ownship into the same stream as the lead. It will also correspond to the out-of-window view, since the lead aircraft is now directly in front of ownship on the same approach path. As the scenario depicts, the ghost and lead symbols will always overlap at the designated in-trail merge point, which denotes the point at which ownship and lead aircraft will merge into the same arrival stream.

There is an advantage to using a ghost aircraft symbol instead of RTAs to guide the flight crew in the merging task. With the ghost symbology, the flight crew maintains spacing basically using the same method as if spacing were occurring in-trail. This enables the two tasks, which present different cognitive challenges, to be performed in a similar manner. Therefore the self-spacing procedure is reduced to a common task, regardless if spacing in-trail or merging.

Recommended Altitude Indication – In the case when aircraft symbols are color coded for altitude, representing the ghost aircraft symbol in a color consistent with the lead aircraft will provide altitude information about the lead.



(a) (b)

Figure 9-11. Merging of Lead Aircraft with Ghost Symbol: (a) Pre-Merging, (b) Ownship Spacing Behind the Ghost. Lead aircraft is at ownship's altitude (white lead aircraft symbol)

Figure 9-12. Example of In-Trail Spacing Behind Lead Aircraft (DAL 893)

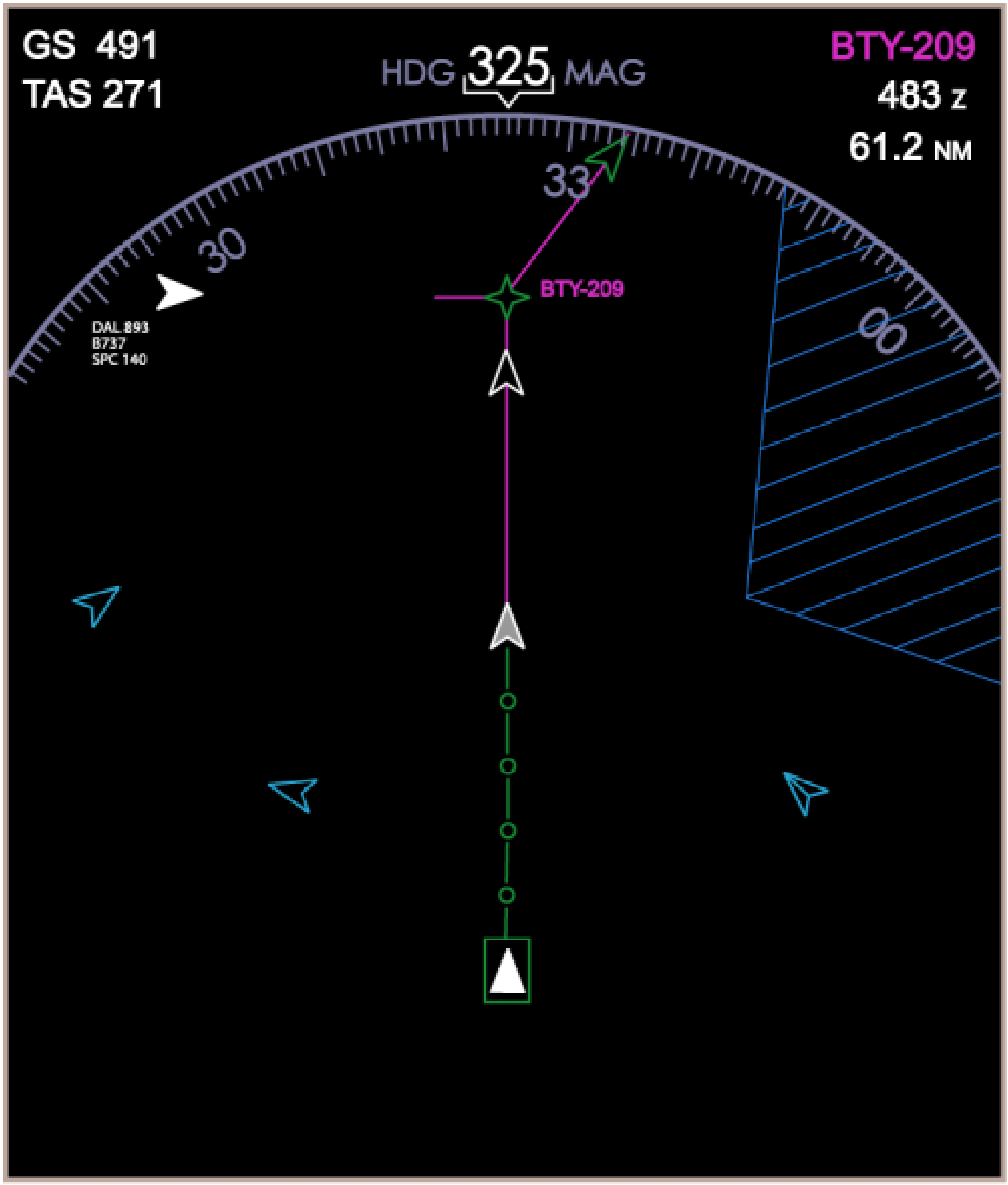


Figure 9-13. Example of Merging Behind Lead Aircraft (DAL 893)

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10. GLOSSARY

Automatic Dependent Surveillance-Broadcast (ADS-B): ADS-B is a function on an aircraft or surface vehicle operating within the surface movement area that periodically broadcasts its state vector (horizontal and vertical position, horizontal and vertical velocity) and other information. ADS-B is automatic because no external stimulus is required to elicit a transmission; it is dependent because it relies on on-board navigation sources and on-board broadcast transmission systems to provide surveillance information to other users.

Airborne Separation Assurance: Provides the pilots with all the critical information necessary to understand the state and condition of the aircraft and the aircraft's external environment. This includes information on the aircraft's relationship to nearby terrain and obstacles, noise sensitive areas, hazardous weather, traffic, and air traffic management clearances and instructions. *This document only addresses the traffic element.*

Alert: A general term that applies to all advisories, cautions, and warning information, can include visual, aural, tactile, or other alerting methods.

Assured Collision Avoidance Distance (ACAD): The minimum assured vertical and horizontal distances allowed between aircraft geometric centers. If this distance is violated, a collision or dangerously close spacing will occur. These distances are fixed numbers calculated by risk modeling and initially will be based on ACAS separation distances.

Assured Normal Separation Distance (ANSD): The normal minimum assured vertical and horizontal distances allowed between aircraft geometric centers. These distances are entered by the pilot or set by the system. Initially the ANSD will be based on current separation standards (and will be larger than the ACAD). In the long term, collision risk modeling will set the ANSD. Ultimately the ANSD may be reduced toward the value of the ACAD.

Collision Avoidance Zone (CAZ): Zone used by the system to predict a collision or dangerously close spacing. The CAZ is defined by the sum of Assured Collision Avoidance Distance (ACAD) and position uncertainties. .

Collision Avoidance Zone (CAZ) Alert: Notifies aircraft crew that a CAZ penetration will occur if immediate action is not taken. Aggressive avoidance action is essential.

Conflict: Predicted converging of aircraft in space and time, which constitutes a violation of a given set of separation minima. (ICAO)

Conflict Detection: The discovery of a conflict as a result of a conflict search. (ICAO)

Conflict Detection Zone (CDZ): Zone used by the system to detect conflicts. The CDZ is defined by the sum of ANSD, navigation and surveillance uncertainties, and trajectory uncertainties. The system is designed to maintain this separation (as measured by the system) between aircraft in a pair.

Conflict Detection Zone (CDZ) Alert: An alert issued at the specified look ahead time prior to CDZ penetration if timely action is not taken. Timely avoidance action is required.

Conflict Detection Zone (CDZ) Penetration Notification: Notification to the crew when the measured separation is less than the specified CDZ.

Conflict Prevention: The act of informing the flight crew of flight path changes that will create conflicts. Prevention guidance is informative in nature, and there is no need for the flight crew to react.

Conflict Resolution: A maneuver that removes all predicted conflicts over a specified "look-ahead" horizon. (ICAO -The determination of alternative flight paths, which would be free from conflicts and the selection of one of these flight paths for use.)

Conflict Search: Computation and comparison of the predicted flight paths of two or more aircraft for the purpose of determining conflicts. (ICAO).

Low Level Alert: An optional alert issued when CDZ penetration is predicted outside of the CDZ alert boundary.

Recovery: A maneuver necessary for resuming a flight plan route or altitude (or other user-desired trajectory) after passing the point of closest approach.

State (vector): An aircraft's current horizontal position, vertical position, horizontal velocity, vertical velocity, turn indication, and Navigational UnCertainty (NUC).

User-Preferred Trajectories (UPT): A series of one or more TCPs that the crew has determined to best satisfy their requirements.

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APPENDIX A

Table A-1. Basic Information Requirements

Information Requirements / Source / Primary or Secondary

	Info. Source			Communication				Component			Import-ance		Display Presentation		
Information Requirements	ATSP	AOC	ADS-B	Datalink Receive	Voice Receive	Datalink Transmit	Voice Transmit	CDTI / CSD	FMS/PFD	Data Input	Primary	Secondary	Always	Selectable	System applied/context
Situation Awareness															
Weather (integrated, long range) (6.1.2)	X		X	X				X			X		X		
Wind (6.1.2)			X	X				X			X		X		
Turbulence (6.1.2)			X	X				X			X		X		
Convective weather (6.1.2)			X	X				X			X		X		
Traffic data (min. 30 minutes ahead)															
Traffic aircraft info (ACID, location) (6.3.2 – 6.23.12)			X	X				X	X		X			X	
Traffic management advisories	X			X								X			X
Intruder info (fused data, sent via datalink from Host)				X							X				X
Airspace Information (6.1, 6.2)															
Waypoint (6.2.1)								X							
RTA (6.2.2)	X			X							X		X		
SUA status (6.1.1)	X			X				X			X			X	
Flow constraints	X			X								X			X
Communication (response to advisories, traffic management directives)	X					X	X					X			X

Table A-2. CE 5 – En Route Free Maneuvering

Information Requirements / Source / Primary or Secondary

	Info. Source		Communication					Component			Import-ance		Display Presentation		
Information Requirements	**ATSP**	**AOC**	**ADS-B**	**Datalink Receive**	**Voice Receive**	**Datalink Transmit**	**Voice transmit**	**CDTI / CSD**	**FMS/PFD**	**Data Input**	**Primary**	**Secondary**	**Always**	**Selectable**	**System applied/context**
Self-Separation Assurance (7.1)															
Trajectories (7.1)															
Ownship								X			X				
Ownship state-Projection Trajectory, based on current position, speed, heading, altitude (7.1.1)								X				X		X	
Ownship intent Trajectories (7.1.1)								X	X			X		X	
Traffic Aircraft Trajectories (7.1.2)			X					X				X		X	
State			X					X				X		X	
Estimated Intent			X					X				X		X	
Inferred Intent			X					X				X		X	
Conflict Detection & Resolution/ACM (7.2)															
Indicate airspace hazard/intruder (7.2.1)				X				X			X				X
Receive intent from traffic			X					X				X		X	
Provides conflict alert (7.2.1)				X				X			X				X
Resolution trajectory (7.2.2)				X	X	X	X	X		X	X			X	X
Status change must be accepted by controller before it takes effect	X			X	X	X	X					X			X
Flight Replanning (Strategic or Tactical) (7.2.2, 8.3)															
Recommended trajectories		X		X				X			X				X
Indication of new trajectory in flight plan								X	X	X	X				X

Table A-3. CE 6 – En Route Trajectory Negotiation

Information Requirements / Source / Primary or Secondary

	Info. Source			Communication						Component						Import-ance		Display Presentation		
Information Requirements	ATSP	AOC		ADS-B	Datalink receive	Voice receive	Datalink transmit	Voice transmit		Nav. Display	CDTI / CSD	FMS	DST	Data Input		Primary	Secondary	Always	Selectable	System applied/context
1. Identify TM situation																				
Identify potential conflicts (7.2.1)																				
Continual updates of flight information from ground					X					X	X						X			
DST – conflict alerting algorithm (7.2.1)										X	X	X	X			X				X
Representation of traffic aircraft on display (6.3.2 – 6.3.12)				X						X	X						X		X	
Representation of conflict location on display (7.2.1)										X	X	X	X			X				X
Representation of traffic aircraft flight plan (7.1.2)				X						X	X								X	
Indication of time to LOS (7.2.1)													X				X			X
ATSP notification of potential violation of aircraft separation. Mode of presentation: data link text? Graphical?	X				X	X				X	X					X				X
Identify potential weather hazards																				
Continual updates of atmospheric information from ground	X	X			X					X	X						X			
ATSP-generated wind/weather forecasts (data link)	X				X					X	X						X		X	
Representation of weather situation on display (6.1.2)				X	X					X	X						X		X	
Indication of level of severity of weather situation on display (6.1.2)				X	X	X				X	X		X				X		X	
2. Review TM Situations																				
Situation Assessment																				
3. Resolve TM Situations (PF or PNF tasks?)																				
Initiate Trajectory Change Request	X						X	X									X		X	
Formulate Efficient Resolution Options (DST provided route)																				
Decision Support Tools (DSTs) - Trajectory prediction tool (7.1.1, 7.2.1)													X						X	
FMS generates trajectory preference and restriction data												X					X		X	

Table A-3. CE 6 – En Route Trajectory Negotiation (Cont.)

Information Requirements / Source / Primary or Secondary

	Info. Source			Communication						Component						Import-ance		Display Presentation		
Information Requirements	**ATSP**	**AOC**		**ADS-B**	**Datalink Receive**	**Voice Receive**	**Datalink Transmit**	**Voice Transmit**		**Nav. Display**	**CDTI / CSD**	**FMS**	**DST**	**Data Input**		**Primary**	**Secondary**	**Always**	**Selectable**	**System applied/context**
Ensures trajectory changes are consistent w/ aircraft performance capabilities – advises pilot accordingly												X	X				X			X
Assess DST trial route																				
Decision Support Tools (DSTs) - Trajectory assessment tool												X	X						X	
Indication of conflict resolution/avoidance of TFM event (7.2.2)										X	X		X				X			X
Indication of new conflicts (7.2.1)										X	X		X			X				X
Modify DST trial route																				
Tools to interact with route														X						
Feedback on whether changes resolve existing conflict/avoid new conflicts										X	X		X				X			X
Store active/provisional trajectories in FMS (**Couluris, p. 28)**												X		X			X		X	
Retrieve active/provisional trajectories in FMS												X		X			X		X	
Accept DST Proposed Route	X	X					X	X				X		X			X		X	
Reject DST Proposed Route	X	X					X	X				X		X			X		X	
Real-Time Collaboration w/ PNF																				
Indication that PNF is creating a trial route (8.1)						X					X		X				X			X
Ability to bring up trial route on some display (8.3)										X	X		X				X		X	
Tools to interact with route (8.3)												X	X				X		X	
Feedback on whether changes resolve existing conflict/avoid new conflicts (7.2.2)										X	X	X	X				X			X
Real-Time Collaboration w/ ATSPs																				
FMS interactive display function to processes negotiation data (8.3)	X										X	X					X		X	
Data link negotiation	X				X		X													

Table A-3. CE 6 – En Route Trajectory Negotiation (Cont.)

Information Requirements / Source / Primary or Secondary

	Info. Source			Communication						Component						Import-ance		Display Presentation		
Information Requirements	**ATSP**	**AOC**		**ADS-B**	**Datalink Receive**	**Voice receive**	**Datalink Transmit**	**VoiceTransmit**		**Nav. Display**	**CDTI / CSD**	**FMS**	**DST**	**Data Input**		**Primary**	**Secondary**	**Always**	**Selectable**	**System applied/context**
Real-Time Collaboration w/ AOCs		X																		
FMS processes negotiation data					X		X					X	X							X
AOC provided plan preferences via data link		X			X							X	X							X
Present trial resolution to ATSP																				
FMS provides pilot/ATSP interface capability							X					X								
Receive ATSP proposed trial route (8.3)	X				X					X	X						X			X
Receive Trajectory Change Clearance	X				X	X										X				X
Enter New Route (if not automatic)												X		X						
Execute New Route												X		X						

Table A-4. CE 11 – Terminal Arrival: Self Spacing for Merging and In-Trail Separation

Information Requirements / Source / Primary or Secondary

	Info. Source			Communication				Component			Import-ance		Display Presentation		
Information Requirements	ATSP	AOC	Aircraft	Datalink Receive	Voice Receive	DatalinkTtransmit	Voice Transmit	CDTI / CSD	FMS/PFD	Data Input	Primary	Secondary	Always	Selectable	System applied/context
Initial Arrival into Terminal Area (9.2.1)															
Convective weather (9.2.1.1)	x			x				x			x		x		
Approach zone boundary (9.2.1.2)	x			x				x			x				x
Approach zone centerline (9.2.1.3)	x			x				x			x				x
Merge points (8.1.4)	x			x				x				x			x
Maneuver in Corridor as Desired/Required (9.2.2)															
Traffic intent information (9.2.2.1)	x							x				x			x
Meet Pre-Merger RTA (9.2.3.1)															
Pre-merger RTAs (9.2.3.1)	x			x	x			x			x				x
Ownship target speed (9.1.1.3)												x		x	
Assigned spacing interval (9.1.1)	x			x	x			x	x	x	x				x
Spacing guidance – free maneuvering (9.1.1)								x	x			x		x	
Levels of engagement (9.1.1.4)								x	x		x			x	x
Auto-disengagement								x			x				x

Table A-4. CE 11 – Terminal Arrival: Self Spacing for Merging and In-Trail Separation (Cont.)

Information Requirements / Source / Primary or Secondary

	Info. Source			Communication				Component			Import-ance		Display Presentation		
Information Requirements	ATSP	AOC	Aircraft	Datalink Receive	Voice Receive	DatalinkTtransmit	Voice Transmit	CDTI / CSD	FMS/PFD	Data Input	Primary	Secondary	Always	Selectable	System applied/context
Merge Behind Assigned Lead (9.2.3)															
Lead aircraft, ID, and type (9.1.1.1)				x				x			x				x
Lead current location, speed, altitude, and heading (9.1.1.1.)												x		x	
Ownship target speed (9.1.1.3)								x				x		x	
Time of merge behind Lead (9.2.3.2)	x			x							x			x	x
In-trail merge point (9.2.3.3)	x			x				x			x		x		x
Spacing guidance – equipped (9.2.3.4)								x	x			x		x	
Maintain In-Trail Spacing (9.1, 9.2)															
Relative distance (9.1.1, 9.2.3.4)	x		x	x	x			x			x		x		x
Relative speed (9.1.1.3)	x		x	x	x			x			x		x		x
Lead aircraft vertical profile			x	x				x				x		x	
Lead aircraft speed profile (9.2.2.1)			x	x				x				x		x	